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Voicing in Dutch

(De)voicing – phonology, phonetics, and psycholinguistics

EDITED BY
Jeroen van de Weijer
Erik Jan van der Torre

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Introduction: Voicing in Dutch

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This volume focuses on the phonology, phonetics and psycholinguistics of voicing-related phenomena in Dutch. Dutch phonology has played a touchstone role in the past few decades where competing theories regarding laryngeal representation have been concerned. The intricacy of different rules manipulating values for the distinctive feature [voice], sometimes from [+voice] to [–voice] and back again, have sparked off different debates, among other things with respect to rule ordering and the 'arity' of the feature [voice], which are currently still in full swing. Outside such discussions about segmental structure proper, processes like final devoicing have played a role in discussions about "evolutionary phonology" (Blevins 2004), where this process is related to differences between stops and fricatives, vowel length and differences in place of articulation (Blevins 204: 103ff). All of these factors play a role in some of the articles in this volume.

This volume adds fuel to these debates on several fronts, both on the level of the facts that competing analyses must account for and by critically examining different analyses that have been proposed. First, the article by Zonneveld reviews the facts of the standard language and presents an overview of formal approaches, from rule-based generative phonology-style ones to various recent OT-based analyses using local conjunction. It lays out the facts regarding the paradoxical facts of the behaviour of the past tense morpheme in Dutch, and the problems this poses for these different approaches. It also presents interesting new material from loanword data and the way these are incorporated, with special attention to voice. Finally, it presents a new OT analysis relying on local conjunction and positional faithfulness which overcomes the problems of past analyses. Importantly, this analysis is able to maintain a monovalent feature [voice].

An area of controversy in the literature is which feature should be based to express voicing contrasts in different languages. For 'aspiration' languages such as English and German, the feature [spread glottis] seems adequate while (pre)voicing languages such as Dutch would seem to require the distinctive feature [voice]. For both features it is possible to argue about the question whether they are binary or unary and whether –if binary– they are initially underspecified or not. This makes predictions about acquisition, in particular with respect to the question which member of a pair of consonants is expected to be acquired first, and which error patterns are expected under any of these approaches. This is the

topic of the contribution by René Kager, Suzanne van der Feest, Paula Fikkert, Annemarie Kerkhoff and Tania S. Zamuner, who investigate these questions for the three languages mentioned above, and conclude that the facts of acquisition indeed point to differential specifications for voicing languages and for aspiration languages. A number of other factors are important in this debate, viz. the role of phonetics (in terms of articulatory effort) and the role of other processes that might interfere with the pattern of errors that children make, in particular consonant harmony.

The third paper, by Marc van Oostendorp, investigates a hitherto unreported aspect of the Dutch voicing rules, viz. the fact that in certain dialects there appear to be exceptions to final devoicing. While devoicing has been investigated from a phonetic point of view and has (sometimes) been found to be incomplete in phonetic detail, certain dialects appear to show systematic exceptions in the synchronic phonology. These exceptions are well-defined: they take place in the case of final labial and velar fricatives in the first person plural. A historical explanation is that these dialects have recently lost (or still variably have) a first person morpheme which 'protects' the final consonant from undergoing devoicing. Synchronically, there are two alternative ways of approaching this: one based on paradigmatic uniformity and one based on abstract underlying representations, both of which present certain problems. It is hoped that facts like these, possibly complemented by other dialectal variations on the theme of voicing, and their analysis, will play a role in future discussions about the facts of Dutch.

Petra M. van Alphen describes the exact phonetic realization of the voiced stops in Dutch, offering an introduction to the phonetic side of the voicing distinction in Dutch. She shows that vocal cord vibration, which is usually assumed to accompany voiced plosives, is frequently absent in these sounds. Surprisingly, it is still possible for Dutch listeners to recognize voiced plosives compared to voiceless plosives. This means that other acoustic cues must be available that aid the perception of voiced plosives, and it entails that voicing is indeed, phonetically, a gradient category.

Wouter Jansen explores the thin (or non-existent) line between phonetics and phonology, in an exploration of the facts of regressive voicing assimilation. He shows that regressive assimilation indeed does take place, but that it has all the hallmarks of a 'low-level' phonetic process, more akin to a coarticulatory effect than a 'real' phonological rule. The question therefore arises in which component of the grammar it should be accounted for.

In the final paper of this volume, Mirjam Ernestus and Harald Baayen take up the fact, referred to above, that final devoicing in Dutch presents a case of phonetically incomplete neutralization (cf. also Port & Leary 2005, where this point is taken as a frontal attack on the main premises of generative phonology). On the basis of a perception experiment, they show that listeners rated different plosives differently according to whether they alternated between voiced and voiceless or not. They take this as evidence that listeners activate morphologically related words when accessing a particular form of a paradigm. If these forms have conso-

nants with different values for [voice] (i.e. if they alternate), the resulting sound will be a ‘compromise’ between voiced and voiceless.

We hope that these papers will serve to describe the state of the art in the phonology and phonetics of Dutch voicing, and to spark off new descriptive, theoretical and experimental research.

References

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Issues in Dutch Devoicing
Positional Faithfulness, Positional Markedness, and Local Conjunction

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The voice phenomena of Dutch are among the most complex and elusive described in the (theoretical) literature of the past few decades (Lombardi 1999, Wetzels & Mascaró 2001). This paper starts by giving a comprehensive overview of the pertinent facts, and then shows how theories such as the rule-based framework and non-linear Principles and Parameter theory have struggled to come to grips with them. The point of the paper's second half is a demonstration of how in Optimality Theory, Lombardi's theory of voice is well equipped to cover Dutch, specifically its awkward language-specific phenomena of fricative devoicing and past tense progressive assimilation, assuming the mechanism of local conjunction (and, in fact, self-conjunction), involving the in itself uncontroversial *LAR ('no voice (on an obstruent)') constraint. Pace earlier accounts, the proposed analysis preserves the privativity of the feature [voice], and – within OT – the 'positional faithfulness' spirit of Lombardi's approach to voice.

1. *Introduction*

Once upon a time (not so long ago), Final Devoicing was a simple phonological process. Presentations involved straightforward alternations such as (Dutch) *han*[t]/*hand-en* 'hand(s)' (or a German, Polish, Russian, or Catalan equivalent), accompanied by the distributional observation that anyway voiced obstruents failed to occur at the end of words, by a phonological rule in the standard format, by the argument that the rule could not be formulated 'the other way around' because of non-alternating forms such as *kant/kant-en* 'side(s)', and by examples of linear ordering involving rules such as regressive assimilation. Currently the same process is a heatedly debated phenomenon, inviting all manner of theoretical and empirical questions. This paper discusses two topics of primary interest from Standard Dutch, a language figuring prominently in the current debate. These are, first, the interaction between a variety of devoicing processes, both syllable-finally and in clusters, and, second, the special status of the past tense. Analyses of these notoriously recalcitrant phenomena will be presented in Optimality Theory, using well-known work by Lombardi as a point of departure. Two OT-theoretical issues will turn out to be relevant. The first is that of 'positional faithfulness' (PF) and (/or) 'positional markedness' (PM), where the analysis proposed follows Lombardi (2001) and Alderete (2003) in assuming that "both PF and PM

constraints a[re] integral parts of the constraint component *CON* [for] different types of evidence” (Alderete 2003:150). Second, because the UG mechanism of local conjunction is central to it, the proposed account will be followed by a brief discussion of ‘metaconstraints’ on local conjunction. (Devoicing being the empirically central notion, the account’s logic will entail conjoining *LAR (a.k.a. *[–son, +voice]) with appropriate other constraints.) Referring to work by Fukazawa & Lombardi (2003) and Ito & Mester (2003), it is argued that ‘M&F’, ‘multiple’ and ‘self-’conjunction are involved in an explanation of the Dutch facts, contributing to a programme that aims to avoid “a large and unwieldy innate component [by] analyz[ing] more complex constraints as combinations of simpler constraints” (Fukazawa & Lombardi 2003:196).

This paper’s exposition starts with three chronologically consecutive types of analysis, proposed within the rule-based framework, non-linear phonology, and so far within Optimality Theory (henceforth OT), in that order. The historical sketch[1] is especially suited to highlight the intricate empirical properties of the Dutch system, and the recurring analytical issues. Sections 2 and 3 introduce the basic generalizations, analysed in a classical rule-based manner. Section 4 describes a (mainly Lombardi’s) non-linear rule-and-repair type analysis in a Principles & Parameters framework, and identifies the typological position of Dutch. Section 5 gives an OT translation of this analysis gleaned from several publications by Lombardi; but this translation remains incomplete where some of the voicing gets tough. Sections 6 and 7 discuss two recent OT analyses by Grijzenhout and Krämer, which cover more complete ground; it will be concluded that these accounts are unsatisfactory, and fall foul of both theoretical and empirical problems. Sections 8 and 9 present this paper’s new analysis of the Dutch facts, extending brief and informal suggestions by Lombardi (1997) into an OT conjunction account.

2. *The basic system*

Introducing the major patterns of Dutch voicing assimilation, consider the early generative rules in (1-4) below, and the data in (5) (all of these are compound words, which relatively straightforwardly give insight into the basic system; see Trommelen & Zonneveld 1979, van der Hulst 1980, Booij 1995, Heemskerk & Zonneveld 2000).

(1) FINAL DEVOICING (henceforth: FINDEV)

[–son] → [–voice] / _____ $

(2) REGRESSIVE VOICING ASSIMILATION (henceforth: RVA)

[–son] → [α voice] / _____ (#) [α voice]

(3) FRICATIVE DEVOICING (henceforth: FRICDEV)

a. [–son, +cont] → [–voice] / [–son] (#) ______

or:

b. [–son, +cont] → [–voice] / [–voice] (#) ______

(4) DEGEMINATION C_i (#) $C_i \rightarrow C_i$

(5)[2]

a.	ijk	ijk-en	ijk-punt	[k-p]	'benchmark'
	straf	straff-en	straf-kamp	[f-k]	'penal colony'
	hand [-t]	hand-en	hand-palm	[t-p]	'palm of the hand'
	proef	proev-en	proef-tijd	[f-t]	'probation'
	strop	stropp-en	strop-das	[b-d]	'necktie'
	lach	lach-en	lach-bui	[ɣ-b]	'laughing fit'
	bloed [-t]	bloed-en	bloed-bank	[d-b]	'blood bank'
	huis	huiz-en	huis-baas	[z-b]	'landlord'
b.	druk	drukk-en	druk-fout	[k-f]	'printing error'
	trompet	trompett-en	trompet-solo	[t-s]	'trumpet solo'
	zorg [-χ]	zorg-en [-ɣ]	zorg-sector	[χ-s]	'social services'
	rib [-p]	ribb-en	rib-fluweel	[p-f]	'(needle) cord'
	grijp	grijp-en	grijp-graag	[p-χ]	'grabby'
	rond [-t]	rond-e	rond-vaart	[t-f]	'round trip by boat'
	drijf	drijv-en	drijf-zand	[f-s]	'quicksand'
	huis	huiz-en	huis-vuil	[s-f]	'household refuse'

The leftmost column of (5) illustrates FINDEV, and the second column the underlying value of the stem-final obstruent before a vowel-initial suffix. The crucial criterion distinguishing (5a) from (5b) is that the (a)-cases have right-hand *plosives* in the internal cluster,[3] whereas the (b)-cases have right-hand *fricatives*: the cluster voice values depend on this difference.

A number of 'ordering relations' hold between the members of the rule set. First, FINDEV operates internally in compounds when the second member is sonorant-initial:

(6)

goud	[-t]	goud-en	goud-ader [-t]	'gold vein'
hand	[-t]	hand-en	hand-rem [-t]	'handbrake'
grond	[-t]	grond-en	grond-wet [-t]	'constitution'
schrob	[-p]	schrobb-en	schrob-net [-p]	'trawl net'
zuig	[-χ]	zuig-en [-ɣ]	zuig-nap [-χ]	'sucking disc'

This implies that, using ordered rules, FINDEV precedes RVA:

(7)

	/ strop#das /	/ hand#palm /	/ bloed#bank /		/ strop#das /
FIND	vac.	t	t	RVA	b
RVA	b	vac.	d	FIND	*p

Second, (3) above contains two versions of the rule of FRICDEV, both of which capture the data in (5b). Their ordering relations differ, however:

(8) a. FRICATIVE DEVOICING: context [–son]

	/ kerk#vorst /	/ rond#vaart /		/ kerk#vorst /	/ rond#vaart/
FRICD	f	f	FIND	vac.	t
FIND	vac.	t	FRIVD	f	f
RVA	vac.	vac.	RVA	vac.	vac.

b. FRICATIVE DEVOICING: context [–voice] (redundantly [–son])

	/ kerk#vorst /	/ rond#vaart /		/ kerk#vorst /	/ rond#vaart/
RVA	g	vac.	RVA	vac.	t
FIND	k	t	FRICD	f	f
FRICD	f	f	FIND	vac.	vac.

When FRICDEV's context mentions [–son] as in (8a), the rule is a statement about the distribution of fricatives, rather than one of assimilation (which is (8b)). But given FINDEV, voiceless clusters are always ensured, and the only ordering requirement is that the (a)-version of FRICDEV precede RVA. The assimilation version of FRICDEV must follow FINDEV. RVA can take two positions, as indicated in (8b). The shape-independent ordering of FRICDEV is the one at the right in both (8a,b).[4]

Finally, the rule set includes DEGEMINATION, which reduces sequences of identical consonants:

(9)	sprint-en	sprint-titel	'sprint title'	t-t → [t]
	kans-en	kans-spel	'game of chance'	s-s → [s]
	spoed-ig	spoed-debat	'emergency debate'	d-d→ t-d → d-d → [d]
	zwijg-en	zwijg-geld	'hush money'	ɣ-ɣ→ χ-ɣ → χ-χ → [χ]
	sport-en	sport-dag	'sports day'	t-d → d-d → [d]
	proev-en	proef-fabriek	'pilot plant'	v-f → f-f → [f]
	dans-en	dans-zaal	'dance hall'	s-z → s-s → [s]

As formulated in (1), FINDEV operates at the syllable- rather than just the word-boundary (Booij 1977, Kooij 1980, Zonneveld 1994). This is supported by the examples in (10) with a word-internal obstruent before a syllable break, which lack a pronunciation difference corresponding to the spelling difference:

(10) [-t$] ad-miraal 'admiral', bad-minton, cad-mium, kid-nap, med-ley, ord-ner 'folder', pred-nison, Bod-nar, Broad-way, Nebukad-nezar, Sverd-lovsk

cf.: at-las, at-leet 'athlete', but-ler, et-nisch 'ethnic', fit-ness, part-ner; alba-tros 'albatross', ma-tras 'mattress', a-drenaline 'adrenalin'

[-p$]	(Aha-)Erleb-nis, Ab-ner, Chleb-nikov, Leib-nitz, Zimbab-we
cf.:	hyp-nose ‘hypnosis’, rohyp-nol
	A-pril, com-plex, bi-bliotheek ‘library’, koli-brie ‘humming bird’
[-f$]	Dubrov-nik, Pav-lov
cf.:	Daph-ne, Heff-ner
	A-frika, moe-flon, ‘moufflon’, li-vrei ‘livery’, na-vrant ‘heartrend-ing’
[-χ$]	dog-ma, enig-ma, frag-ment, pyg-mee ‘pygmy’, mag-neet ‘magnet’, preg-nant
cf.:	drach-me ‘drachma’, strych-nine, tech-niek ‘technology’
	fla-grant, i-glo ‘igloo’, man-grove, pel-grim ‘pilgrim’, retro-grade

Thus in Dutch *Britney* and *Sidney* are a perfectly rhyming pair. These data imply that FINDEV follows the syllabification procedure of the grammar, independently ensuring that plurals like *han$d-en* coexist with singulars like *han*[t].

The rule set in (1-4) is pervasive in the language. In addition to the examples provided so far, the regressive assimilation vs. fricative devoicing pattern occurs inside underived words, too, as shown in (11) (examples taken from a slightly different discussion in Zonneveld 1983).

(11)a.

plosive right				*fricative right*	
pasta	‘pasta’	labda	‘lambda’	fatsoen	‘decency’
octrooi	‘patent’	anekdote [gd]	‘anecdote’	rapsodie	‘rhapsody’
wodka [tk]	‘vodka’	dukdalf [gd]	‘mooring post’	taxi	‘taxi’
dochter	‘daughter’	asbest [zb]	‘asbestos’	fosfor	‘phosphorus’
moskee	‘mosque’	rugby [ɣb]	‘rugby’	ischias [sχ]	‘sciatica’
			*- but no cases like: *fa[dz]oen*		

b.

plosive right			*fricative right*		
feest	‘party’	fees$t-en (pl.)	fiets	‘bicycle’	fiet$-sen (pl.)
kiosk	‘kiosk’	kios$k-en (pl.)	arts	‘doctor’	art$s-en (pl.)
hoofd	‘head’	hoo[v]$d-en (pl.)	loods	‘pilot’	loo[t]$s-en (pl.)
smaragd	‘emerald’	smara[ɣ]d-en (pl.)	eclips	‘eclipse’	eclip$s-en (pl.)
abt	‘abbot’	ab$d-ij ‘abbey’	koets	‘coach’	koet$s-ier ‘coachman’
			*- but no cases like: fie[ts] ~ *fie[d$z]-en*		

The data in (12) below briefly illustrate the applicability of the rules at the phrase level (the ^ symbol indicates the assimilation site; cf. Nespor & Vogel 1986, Booij & Rubach 1987, Trommelen 1993, Menert 1994, Ernestus 2000).

(12)	klap#deur	[b-d]	'swing door'	
	- Ik klap ^ deur 5 open			[b-d]
	[lit.: I swing door #5 open]			
	rond#vaart	[t-f]	'round trip (by boat)'	
	- Het schijnt dat hij rond ^ vaart			[t-f]
	[lit.: It seems that he around sails]			
	wand#tegel	[(d)-t]	'wall tile'	
	- Hij wil dat ik de wand ^ tegel			[t]
	[lit.: He wants that I the wall tile]			

Finally[5], as affixed forms play an important role in the remainder of this paper, their properties are discussed separately in the next section.

3. *Affixed forms*

The list in (13) below exhaustively mentions all relevant syllabic (vowel-containing) *suffixes*, showing that the voicing rule set operates when the rightmost obstruent of the cluster is affixal (Booij 1977, Trommelen & Zonneveld 1979); just as in (5), the data are subdivided into (a)- and (b)-cases depending on the manner feature of the right-hand obstruent:

(13)[6] a.	rijk-e	'rich, INFL'	rijk-dom	[g-d]	-dom N	'richness'
	paus-en	'popes'	paus-dom	[z-d]		'papacy'
	liev-e	'sweet, INFL'	lief-de	[v-d]	-de N	'love'
	zess-en	'sixes'	zes-de	[z-d]	-de Num	'sixth'
	vijv-en	'fives'	vijf-de	[v-d]		'fifth'
	wijd-e	'wide, INFL'	wijd-te	[(d)-t]	-te N	'width'
	ruig-e [ɣ-]	'rough, INFL'	ruig-te	[χ-t]		'roughness'
	berg-en [ɣ-]	'mountains'	ge-berg-te	[χ-t]	ge-X-te N	'mountain range'
	Elizabeth	'Elisabeth'	Els-ke	[k-t]	-ke N (names)	'little Lizzy'
	denk-en	'to think'	denk-baar	[g-b]	-baar A	'imaginable'
	buig-en [ɣ-]	'to bend'	buig-baar	[ɣ-b]		'pliable'
b.	hand-en	'hands'	hand-zaam	[t-s]	-zaam A	'manageable'
	volg-en [ɣ-]	'to follow'	volg-zaam	[χ-s]		'obedient'
	vriend-en	'friends'	vriend-schap	[t-s]	-schap N	'friendship'
	broed-en	'to hatch'	broed-sel	[t-s]	-sel N	'hatch'
	stijv-en	'to starch'	stijf-sel	[f-s]		'starch'
	acht-en	'eights'	acht-ste	[t-s]	-ste Num	'eighth'
	twintig-en [ɣ-]	'twenties'	twintig-ste	[χ-s]		'twentieth'
	leid-en	'to lead'	leid-ster	[t-s]	-ster N	'leader, FEM'
	schrijv-en	'to write'	schrijf-ster	[f-s]		'writer, FEM'

Next, (14) lists all relevant – but less numerous – syllabic *prefixes*, to the same effect:

(14)	brand-en	'to burn'	ont-branden	[d-b]	ont-	'to ignite'
	vangen	'to catch'	ont-vangen	[t-f]		'to receive'
	vader	'father'	aarts-vader	[ts-f]		'patriarch'
	in-dicatie	'indication'	ab-dicatie	[b-d]	ab-	'abdication'
	re-solutie [–z]	'resolution'	ab-solutie	[p-s]		'absolution'
	verbaal	'verbal'	ad-verbium	[t-f]	ad-	'adverb'
	de-vies	'motto'	ad-vies	[t-f]		'advice'
	re-ductie	'reduction'	ob-ductie	[b-d]	ob-	'autopsy'
	in-structie	'instruction'	ob-structie	[p-s]		'obstruction'
	trans-missie	'transmission'	trans-vaal	[t-f]	trans-	'Transvaal'
	trans-lucide	'translucid'	trans-ductie	[z-d]		'transduction'

When a vowelless obstruent suffix is attached to an obstruent-final stem, the result is a completely voiceless final obstruent cluster, as shown in (15):

(15) a.	schrijv-en	'to write'	schrif-t (-en)	[f-t]	-t N	'(hand) writing'
	scrib-ent	'writer'	scrip-t (-en)	[p-t]		'script'
	corrump-eren	'to corrupt'	corrup-t (-e)	[p-t]	-t A	'corrupt'
	krabb-en	'to scratch'	krab-t	[p-t]	-t	2/3sg. present tense
	wrijv-en	'to rub'	wrijf-t	[f-t]		
	bonz-en	'to hammer '	bons-t	[s-t]		
	houd-en	'to hold'	houd-t	[(d)-t]		
	mog-en	'may'	moch-t (-en)	[χ-t]	-t	irregular past tense
	deug-en	'to be good'	deug-d	[χ-t]	-d N	'virtue'
			deug-d-en	[ɣ-d]		'virtues'
b.	broed-en	'to hatch'	broed-s	[t-s]	-s A	'broody'
	zondag-en	'Sundays'	zondag-s	[χ-s]		'on Sunday'
	trend-y	'trendy'	trend-s	[t-s]	-s	PL in loans
	snobb-isme	'snobbery'	snob-s	[p-s]		
	Fredd-ie	'Freddy'	Fred-s	[t-s]	-s	POSS
	Bobb-ie	'Bobby'	Bob-s	[p-s]		
	leid-en	'to lead'	leid-s (-man)	[t-s]	'linking'-s	'leader'
	kalv-eren	'calves'	kalf-s (-lever)	[f-s]		'calf's liver'
	vond-en	'found, PL'	vond-st (-en)	[t-s]	-st N	'findings'
	hard-e	'hard, INFL'	hard-st (-e)	[t-s]	-st SUPERL	'hardest'
	erg-e	'bad'	erg-st (-e)	[χ-s]		'worst'

There are two possible ways of accounting for these cases: by FINDEV > RVA, or by having FINDEV apply in one sweep to any sequence of obstruents ($[–son]_1$) before a syllable boundary or 'in a Coda'. The Coda possibility presupposes a usually assumed two-step syllable structure procedure fully preceding FINDEV. At 'level 1' the Rhyme constituent can maximally contain just a single consonant (Trommelen 1983, Kager & Zonneveld 1986, Zonneveld 1993, Fikkert 1998), implying that the rightmost obstruent of a cluster, and in some cases all obstruents, are in a post-Coda Appendix; then at 'level 2' restructuring takes place (Booij

1977, Nespor & Vogel 1986, Booij & Rubach 1987, Booij 1988), the result used as input to FINDEV. The matter of Dutch obstruent prefixes will be separately addressed in section 9 below.

The most complex behaviour of all affixes is exhibited by the past tense suffix. First of all, the suffix's properties in neutral sonorant-final stem cases are those below:

(16) Infinitive: *noem-en* 'to name'
- past tense: *noem-d-e* = stem + '*-d-e* suffix'
- past participle:[7] *ge-noem-d* [–m-t] by FINDEV, inflected form *ge-noem-d-e*

Likewise: *ski-en* 'to ski', *zoen-en* 'to kiss', *meng-en* 'to mix', *wándel-en* 'to walk', *ádem-en* 'to breathe', *omhéin-en* 'to fence in', *tuiníer-en* 'to practise gardening', etc.

The past participle involves the discontinuous affix *ge-X-d*. The *–d* element undergoes FINDEV when absolutely final (in the past participle), and is voiced when followed by an inflectional *–e*. Unexpectedly, even though the suffix is a plosive, it itself *undergoes* assimilation when the stem is obstruent-final; cf. the near-minimal pair in (17a). This pattern is completely systematic, as illustrated by the additional examples in (17b).

(17) a. infinitives: *krabb-en* 'to scratch', *klapp-en* 'to applaud'
- past tense: *krab-d-e* = stem + *-d-e* vs. *klap-t-e* = stem + *-d-e*
- past participle: *ge-krab-d* [–p-t], inflected form *ge-krab-d-e*
  ge-klap-t [–p-t], inflected form *ge-klap-t-e*

b.

werk-en	'to work'	werk-t-e	[k-t]	ge-werk-t	[k-t]
stamp-en	'to stamp'	stamp-te	[p-t]	ge-stamp-t	[p-t]
tobb-en	'to worry'	tob-d-e	[b-d]	ge-tob-d	[p-t]
plant-en	'to plant'	plant-t-e	[(t)-t]	ge-plant	[(t)-t]
wens-en	'to wish'	wens-t-e	[s-t]	ge-wens-t	[s-t]
juich-en	'to cheer'	juich-t-e	[χ-t]	ge-juich-t	[χ-t]
golv-en	'to undulate'	golf-d-e	[v-d]	ge-golf-d	[f-t]
kapseiz-en	'to capsize'	kapseis-d-e	[z-d]	ge-kapseis-d	[s-t]
volg-en [ɣ-]	'to follow'	volg-d-e	[ɣ-d]	ge-volg-d	[χ-t]
voed-en	'to feed'	voed-d-e	[(d)-d]	ge-voed	[(d)-t]

Assimilating progressively, this suffix[8] behaves differently from all other voiced plosive-initial suffixes (*-dom*, *-de*$_{\mathrm{Num}}$, *-d*, *-baar*). Trommelen & Zonneveld (1979) and Zonneveld (1982) argue that what is observed here is, uniquely, a plosive showing the assimilatory properties of a fricative. Their analysis assumes the following steps. The underlying form of the suffix is the voiced fricative /-ð/; after an obstruent this form assimilates progressively, by version (3b) of FRICDEV men-

tioning [–voice], producing /-θ/; at the end of the rule-based derivations the abstract fricatives are converted into the plosives required by the language.

In any analysis of the past tense, a separate concern is how to block FINDEV in this context: FINDEV (i) applies at the syllable edge, and (ii) crucially feeds the [–voice] version of FRICDEV (cf. (8b)) assumed for past tense assimilation. The derivations of a compound form such as *volg-zucht* 'submissiveness' ([χ-s]) and a suffixed form like *volg-zaam* 'docile' (also [χ-s], cf. (13)) critically rely on this ordering; but the past tense of the associated verb is *volg-de* [ɣ-də], not *[χ-tə]. Trommelen and Zonneveld's analysis blocks FINDEV by invoking pre-FINDEV resyllabification. They propose that inflectional paradigms of Dutch weak verbs contain a 'theme vowel', effectuating a syllabification automatically preempting FINDEV: /vol$ɣ-e-ð-e/. They provide independent evidence for this theme-vowel (which will be returned to in section 8 below); a separate rule deletes it later in the derivation (prior to FRICDEV, which needs adjacent obstruents). Some typical derivations[9] look as follows:

(18)	/ volɣ -e -ð -e /	/ juix -e -ð -e /	/ volɣ - zaam /
Syllabif	l$ɣ	i$x	lɣ$z
FinD	n.a.	n.a.	x
Theme-V Del	∅	∅	n.a.
FricD using [–voice]	n.a.	x θ	x s
late rule	ɣ d	x t	n.a.

Clearly this analysis is highly abstract in the sense of the 'abstractness debate' in 1970's and 1980's phonology (see e.g. Kiparsky 1982), and hence not uncontroversial. The alternative is simply a rule of progressive assimilation for the past tense suffix alone, as in (19) (van der Hulst & Kooij 1981, Berendsen 1983, 1986), separately preceding the set in (1-4).

(19) [–son, PT] → [–voice] / [–voice] _____

In terms of rule-based phonology, however, it might be considered a drawback that the formal similarity of this rule to FRICDEV is left unexpressed, i.e., an opportunity to formally unify the two cases is left untaken. Moreover, such a rule's use of the feature value [–voice] has been argued to be unavailable to phonology, as discussed in the next section.

4. *Non-linear Phonology*

Lombardi (1991, 1995) formulates a typology of voicing assimilation languages in a non-linear Principles and Parameters (P & P) framework. Her work, which is central to virtually all generative-theoretical discussions on the feature [voice] of the past decade, basically renders the above analysis of Dutch into P & P. As a point of departure, consider some straightforward examples of regressive assimilation involving stops:

```
(20)[10]   voi                 voi    voi          voi          Voice tier
            |                   |      |            |
           Lar                 Lar    Lar          Lar          Laryngeal node
            |                   |      |            |
      strop - das           bloed   -  bank    hand – palm
output:  [b - d]                [d - b]           [t - p]
```

Lombardi’s account uses the following components:
- (i) a single-valued (‘privative’) feature [voice] (following a proposal by Ito & Mester 1986 towards incorporating this notion in UG);
- (ii) a universal markedness convention specifying obstruents as voiceless ‘by default’ in the output when not [voice];
- (iii) a universal constraint, to the effect that [voice] be ‘licensed’ in Onsets only (in fact just in the context [___ [+son]]$_\sigma$); this constraint is available to languages but not necessarily present in all of them, i.e. it is a parametric option;
- (iv) Spread-[voice], also a parametric option (possibly a language-particular setting of the universal SPREAD parameter of Piggott 1988); SPREAD-voice is always regressive.

Examples such as those in (20) run as follows. First, syllable-final [voice] features are declared void by licensing, depriving the rightmost two examples of their compound-internal word-final feature. Second, SPREAD-voice regressively distributes [voice] onto the clusters of the leftmost two examples. Finally, the markedness convention specifies both members of the cluster in the third example as voiceless. Delinking by the licensing convention and end-of-the-line insertion of voicelessness is how this analysis deals with cases of final devoicing (*hand* = *han*[t]), for which there is no separate rule. Delinking (=Licensing) > Spreading > default is the natural order of the components of this analysis.

Fricative devoicing does not follow naturally from these proposals: the analysis resorts to a language-specific rule.[11] Since [–voice] is theoretically impossible, the non-linear version of FRICDEV must be the equivalent of (3a), delinking licensed [voice] after [–son], as in (21a):

```
(21)  a. rule (non-linear FRICDEV):      b. examples:
         [–son] [–son, +cont]            / stop # verf /     / rond # vaart /
                    ǂ                              ǂ                 ǂ    ǂ
                   voi                            voi               voi  voi
```

Licensing, FRICDEV, and the markedness convention derive an entirely voiceless cluster in both cases of (21b). Lombardi (1991:51) correctly observes that non-linear FRICDEV “must apply before the spreading of [voice]”.

The assumption of impossible [–voice] begs the question of the fate of the past tense suffix. Not unproblematically, the above analysis is more strongly geared towards voiceless clusters than before: both licensing and FRICDEV (in the context of [–son]) predict voicelessness. (22a) below shows Lombardi’s solution for the past tense:

(22) a. / krab - ð - e / b. / bloed # bank / / huiz # baas /
Fusion
voi voi voi

Fusion merges the [voice] feature of two immediately adjacent obstruents, here pre-empting any delinking, whether by licensing (**jui*[ɣ]-*de*, cf. (18)) or by FRICDEV (**zor*[χ]-*te*). Although primarily intended for the past tenses, Lombardi (1991:46-51) points out that fusion has a beneficial side effect in compounds such as those in (22b) (originally the middlemost in (20)): the “rather futile devoicing and revoicing does not in fact take place: rather, [I submit] that [voice] specifications that become adjacent fuse into one linked structure, which is parasitically licensed just like the structure created by spreading.” This can be seen as an attempt at avoiding a non-linear variety of the Duke of York gambit (recall section 2, fn. 4).

This side effect also has a downside, however. Cases such as *rond-vaart* [t-f], *drij/v/-zand* [f-s] and *hui/z/-vuil* [s-f] with a right-hand fricative should end up with voiceless clusters, cf. (5b) and (21), from underlyingly completely voiced ones. In order to cover these, Lombardi proposes the following (1995:58-59): “If Laryngeal Nodes fuse automatically and the linked structure escapes [[Voice]-Licensing], how can Progressive Assimilation apply in a form like (22f) [/huiz+vuil/ → [–sf-]]? The answer is that all of those forms have a compound-type boundary. In this form, /z/ has already devoiced before the level where [/vuil/] is added, as we can see from the fact that morpheme-final obstruents are voiceless in a compound even when the second member is vowel-initial: (27) *huid+arts* → *hui*[t]*arts*. So there is no point in the derivation of (22f) at which two voiced consonants come together, and so there is no Fusion.” This is having your cake to eat it, however: the analysis cannot simultaneously have fusion in compounds such as *bloed-bank* and *hui*/z/-*baas* avoiding Duke derivations, and no fusion in compounds such as *hui*/z/-*vuil* and *rond-vaart* assuming prior application of the licensing convention. Noting this, Wetzels & Mascaró (2001:233-234), in a paper extensively reviewing the tenets of Lombardi’s work[12], conclude that fusion fails, that where fusion fails there is no analysis of the Dutch past tense, and that the only remaining option involves a rule mentioning [–voice], i.e. a separate past tense assimilation rule as in (19), discrediting the privative [voice] hypothesis. This seems premature. Since the compound derivations are technically perfect without it, fusion could be formulated so as to cease to be relevant to the compounds, for instance as a morphologically conditioned language-specific rule, suggesting that considering it a universal may have been overly ambitious.[13]

A small handful of analyses have been proposed in the literature as rivals to Lombardi’s account of the Dutch past tense. Booij (1995:61-62) maintains binary [±voice], and proposes that the suffix be underspecified for [voice]. Such language-specific three-way contrasts encoding idiosyncratic behaviour are not uncontroversial.[14] Even if accepted, however, getting the voice values right in the appropriate contexts is now a serious problem: his rule progressively assimilating

past tense *-d* to the final *sound* (rather than just obstruent) of the stem seems decidedly odd from a typological point of view. Devoicing is blocked by fusion, but the implications for Dutch compounds are left undiscussed. Iverson & Salmons (2003) propose a rule delinking underlying past tense /-d/'s complete Lar-node, after [–son] just as in (21a); it triggers a process finding /-d/ a new Lar-node, succeeding to the left, *-d* adopting the contents of that node. Spreading is blocked because it needs Lar-nodes, and FRICDEV is irrelevant because the suffix is not a fricative.[15] The redeeming features of this analysis are that it lacks both fusion and abstractness, and maintains privative features (cf. fn. 12). The following properties seem seriously questionable, on the other hand: the blocking of devoicing in the past tense is left undiscussed; the past tense delinking rule duplicates FRICDEV's context; and it deriving an intermediate Lar-less obstruent can only be seen as a brute force step, with the sole function of enabling 'progressive spreading': this particular intermediate type of node structure has no other purpose in the phonology of the language.

Thus the Dutch past tense remains a descriptive challenge, also in non-linear phonology. This aside, one of the attractive features of Lombardi's work is the author's attempt at sketching the contours of a typological theory of voicing assimilation languages of the world, by a small set of universal parameters.[16] In Lombardi's P & P classification, Dutch shares a slot with Polish and Catalan, which have word-final devoicing (the Licensing constraint) and Spreading; German has just the first, it has no Spreading. Languages which have internal assimilation but no word-final devoicing have extraprosodic final obstruents: an example may be Yiddish. English has voiced and voiceless obstruents in opposition to one another in both margins of the syllable, so it has neither Spreading nor licensing.[17]

5. *An analysis in Optimality Theory (L)*

Lombardi (1999) develops an account of voicing assimilation within Optimality Theory (Prince & Smolensky 1993, McCarthy & Prince 1993a,b), using universal but violable constraints, and building on the non-linear analysis outlined in the previous section. Dutch is dealt with incompletely: regressive assimilation is covered, but fricative devoicing and past tense assimilation are no more than hinted at. The incompleteness is a result of the overall approach, as acknowledged by Lombardi.

First, [voice] continues to be privative. Second, among the universal OT constraints, the analysis contains two markedness constraints, one stating that voiced is marked relative to voiceless ('lacking [voice]'), the other that assimilation is natural among adjacent obstruents (the OT version of Spreading):

(23) *LAR: Do not have laryngeal features
AGREE: Obstruent clusters agree in voicing

In the AGREE constraint the notion of 'obstruent cluster' functions as the, possibly preliminary, 'domain' of the constraint (for further discussion, see Lombardi (1999:272), and below).

Third, two faithfulness constraints counteract phonological activity in a grammar:

(24) IDLARYNGEAL: Consonants are faithful to underlying laryngeal specification.
IdONSETLAR: Onset consonants are faithful to underlying laryngeal specification.

IDONSETLAR is the OT version of Onset-[voice] licensing (so again 'onset' implies the [___ [+son]]$_\sigma$ context). It is linked to work by Beckman (1995, 1998) and others who proposed similar 'positional faithfulness' constraints "as a way of accounting for the observation [...] that languages may maintain a distinction only in prominent positions and neutralize it elsewhere" (Lombardi 1999:270-271).

A language like Dutch uses these constraints in the following manner:

(25) a. Final Devoicing

/ hand /	AGREE	IDONSLAR	*LAR	IDLAR
[hand]			*!	
☞ [hant]				*

b. Regressive voicing assimilation: voiced

/ strop # das /	AGREE	IDONSLAR	*LAR	IDLAR
strop # das	*!		*	
strop # tas		*!		*
☞ strob # das			**	*

c. Regressive voicing assimilation: voiceless

/ hand # palm /	AGREE	IDONSLAR	*LAR	IDLAR
hand # palm	*!		*	
hand # balm		*!	**	*
☞ hant # palm				*

Thus, in this framework:
- regressive assimilation = high ranked AGREE and IDONSLAR,
- contrast (in onsets) = IDONSETLAR » *LAR, and
- (final) devoicing = (IDONSETLAR ») *LAR » IDLAR.

One of the most important aspects of Lombardi's approach is her factorial typology of languages, using the above constraints. Dutch belongs to the class of (26a) below:

(26) a. AGREE, IDONSETLAR » *LAR » IDLAR — Dutch, Polish
= (syllable) final devoicing, regressive voicing assimilation

b. AGREE, IDONSETLAR » IDLAR » *LAR — Yiddish
= no final devoicing, regressive voicing assimilation

c. IDONSETLAR » *LAR » AGREE, IDLAR — German
= (syllable) final devoicing, no voicing assimilation

d. IDLAR » AGREE, *LAR (ranking of IDONSETLAR irrelevant) — English, Georgian
= no final devoicing, no voicing assimilation

e. *LAR » IDLAR, IDONSETLAR (ranking of AGREE irrelevant) — Maori, Arabela
= no voice distinction at all (no voiced obstruents)

f. AGREE, IDLAR » *LAR » IDONSETLAR — Swedish
= no final devoicing, bidirectional spread of voiceless

Lombardi points out that the overall constraint system[18] makes an empirical prediction regarding the direction of voicing assimilation in languages (1999:287-290):

(27) The licensing analysis of Lombardi (1991, 199[5]) goes some way towards explaining the dominance of laryngeal contrasts in the onset over those in the coda. However, in that analysis the rule of voicing assimilation still must stipulate direction. The well-formedness constraints alone could not prevent coda voiced obstruents from spreading [voice] to an onset, as this would result on the surface in the same well-formed doubly linked structure that results from regressive assimilation.

Thus, the earlier analysis still needs to resort to stipulation to account for the fact that voicing assimilation is overwhelmingly regressive in direction. [...] In contrast, the present analysis predicts that when only these basic constraints are sufficiently high ranked to be active, only regressive assimilation will be possible.

However, progressive assimilation is not completely ruled out:

(28) [B]ecause the AGREE constraint is not inherently directional, progressive assimilation will still be possible, but only if higher-ranked constraints intervene to override the effects of IDONSLAR. [...] In all languages I know of where voicing assimilation simply applies to all clusters with no further restrictions on environment, it is regressive. All the cases of progressive assimilation I have found, in contrast, have some further morphological or phonological restrictions on the context of assimilation, showing the action of additional constraints.

As an illustration, she gives the example of the progressive voicing assimilation found in the English plural: *cat*-[s] vs. *dog*-[z]. Pre-OT Lombardi (1991:170) already invoked the universal constraint in (29) (due to Mester & Ito 1989, referring back to Harms 1973 – hence called Harms's Generalization – and Greenberg 1978):

(29) Harms's Generalization:
Voiced obstruents must be closer than voiceless obstruents to the syllabic nucleus.

Assuming /-z/ as the suffix's underlying form, as is commonly done, this constraint enforces /kæt-z/ becoming [kæt-s]. She adds that, if the English plural effect "were a language-particular rule, we would expect to find a language exactly like English except without this rule, which would have examples like **wim*[pz]. However, such examples do not occur in any language". Employing the same constraint in OT, Lombardi (1999:288-289) gives English tableaux such as those in (30):

(30) a. *cat*-[s] in English

/ cat - z/	HAGEN	IDLAR	*LAR
cat - z	*!		*
cad - z		*	*!*
☞ cat - s		*	

b. *dog*-[z] in English[19]

/ dog - z/	HAGEN	IDLAR	*LAR
☞ dog - z			**
dok - s		*!	

This example shows how progressive assimilation can be enforced by high-ranking an independent constraint, in this case Harms's Generalization.[20] Notice at the same time, however, that – *pace* Lombardi – this English case is not typical of the ones described in (27-28). English is not a regressive assimilation language, so the case does not show how Harms enforces 'progressive overriding regressive': it shows Constraint » IDLAR rather than Constraint » IDONSETLAR in a situation in which IDONSETLAR is immaterial. Moreover, if Harms is, as claimed, not violated "in any language" (Lombardi 1995:62) it is a candidate principle for inclusion in the Gen component of the grammar, violations then not even being members of the candidate set in any language.

Let us then, even more curious than before, turn to the form a description of the Dutch facts takes in this framework. Dutch is included (Lombardi 1999:289-290) in a small list of languages claimed to illustrate (28). It is described relatively succinctly as follows: "Other cases of progressive assimilation similarly show restrictions to special circumstances. [...] Dutch [shows them] when the second consonant is a fricative (see Lombardi 1997 for data and analyses) [and in the] past tense morpheme (Lombardi 1991, [1995])".[21] Lombardi (1997) of this quote is an unpublished paper in which a reinterpretation of Dutch fricative devoicing is suggested in terms of the following OT constraint:

(31) FRICATIVEDEVOICING: * [–son] [–son, +cont, voice]

This constraint must be high-ranked in order to enforce a progressive assimilation effect:

(32) Dutch Fricative Devoicing using (31): *hand-zaam* (*rond-vaart*, etc.)

/ hand - zaam /	AGREE	FRICDEV	IDONSLAR	*LAR	IDLAR
hant - zaam	*!	*		*	*
hand - saam	*!		*	*	*
hand - zaam		*!		**	*
☞ hant - saam			*		*

In this tableau, FRICATIVEDEVOICING (FRICDEV) is in the lowest position it can take, it could also be first. When the second obstruent in the cluster is a plosive, FRICDEV is irrelevant and the tableaux in (25) hold. Lombardi (1997:12-13) concludes that

(33) [c]learly more needs to be done to confirm the validity of [(31)] as a part of UG. [...]
[It] may actually be some kind of constraint interaction effect, and if so the markedness of voiced fricatives is likely to be involved. Although all voiced obstruents are marked, it appears that voiced fricatives are more marked than voiced stops. [In the past tense s]ome constraints specific to this morpheme or to the root/affix distinction are presumably involved.

In sections 8 and 9 these speculative remarks will underlie this paper's new analysis of Dutch voice. Before that, however, we will consider two existing OT analyses of the facts by Grijzenhout and Krämer.

6. *An analysis in Optimality Theory (G & K I)*

Grijzenhout and Krämer (henceforth G & K) continue the discussion of Dutch where Lombardi abandons it: they aim at a full analysis of the Dutch facts (including some aspects of cliticization, but on this see fn. 5). In fact, G & K produce two different analyses in three papers of the same title. The first analysis is that of G & K (1998a), and it will be discussed in this section. The second analysis appears in two different variants in G & K (1998b, 2000), and it will be discussed in the next section.

The common core of all of G & K's analyses is depicted in tableaux (34a,b). Comparing (32) above, a pair of alternative constraints exactly occupies FRICDEV's spot.

(34) a. Dutch regressive assimilation (G & K core proposal): *strop-das* (*denkbaar*, etc.)

/ strop - das /	AGREE	ID-ω-ONSET STOPLAR	ω-FINAL DEVOICING	IDLAR	*LAR
strop - das	*!				*
strob - tas	*!	*	*	*	*
strop - tas		*!		*	
☞ strob - das			*	*	**

b. Dutch fricative devoicing (G & K core proposal): *hand-zaam* (*rondvaart*, etc.)

/ hand - zaam /	AGREE	ID-ω-ONSET STOPLAR	ω-FINAL DEVOICING	IDLAR	*LAR
hant - zaam	*!			*	*
hand - saam	*!		*	*	*
hand - zaam			*!		**
☞ hant - saam				*	

All regressive assimilations follow from a STOP variant of IDONSETLAR, confined to the onset of prosodic Words (ω's), in combination with AGREE. Fricative Devoicing is enforced by FINALDEVOICING, in crucial combination with the two earlier constraints.

The constraint details of this alternative proposal work out as follows:

(35) a. *LAR is maintained, but two 'relativized' variants are added (G & K 1998a:14):
- No laryngeal features: at the end of syllables = SYLLABLE-FINAL DEVOICING
- No laryngeal features: at the end of words = PROSODIC WORD-FINAL DEVOICING

b. The constraint IDSTEMLAR is introduced: segments of a stem are faithful to their underlying specification (G & K:1998a:25-26)

c. FRICATIVE DEVOICING is abandoned because, from Lombardi's (33), G & K (1998a:21) draw the conclusion that the constraint is "not very elegant"; its place is taken by WORD-FINAL DEVOICING in combination with (preceded by) the constraint in (i) below, which is proposed to be the "local conjunction" of (ii) and (iii) (which are therefore also in G & K's UG constraint pool):
(i) IDENTITY PROSODIC-WORD ONSET STOP [LAR] (G & K 1998a:24)
(ii) IDENTITY STOP [LAR] (G & K 1998a:23)
(iii) IDENTITY PROSODIC-WORD ONSET [LAR] (G & K 1998a:23).

Local conjunction is the procedure by which a ‘conjoined constraint’ is created on the basis of two independently existing constraints. The procedure was first proposed in unpublished work by Smolensky (1995), and entails that the conjoined constraint is violated by a candidate which violates both parent constraints together (also see McCarthy 1999:365, and 2002a:18). We will return below to G & K’s application of conjunction to Dutch. Lombardi’s IDONSETLAR constraint does not figure in G & K tableaux, but it remains in their UG pool for reasons of factorial typology, cf. Grijzenhout (2000) and below.

Some of G & K’s constraints rely on the introduction – next to the Syllable (σ) – of the phonological domain of the Prosodic Word (ω), independently motivated for Dutch in work in Prosodic Phonology such as Nespor & Vogel (1986) and Booij (1988). These authors assume that Dutch compounds exist not only of combinations of morphological words, but also of Prosodic Words, which in Prosodic Phonology serve as domains of phonological processes. Furthermore, a distinction is made between two types of affixes: some affixes are themselves ω’s, whereas others are included *in* ω’s. A vowel-initial suffix like plural or infinitival *-en* is a suffix of the latter type, so [vɔlɣ-en] is a single ω. (In itself this is not sufficient to block final devoicing, because this requires the substring [...l$ɣ...], but ω also functions as the domain within which (re-)syllabification takes place.) Suffixes assumed to be separate ω’s include those below, where equivalent (similarly structured) compounds are added for comparison (non-glossed data are taken from section 1):

(36) a.	[schub]ω-[achtig]ω	‘squamous’	[goud]ω-[achtig]ω	‘golden’	
	[paus]ω-[dom]ω	[denk]ω-[baar]ω		[vriend]ω-[schap]ω	
	[werk]ω-[zaam]ω	[hand]ω-[zaam]ω		[volg]ω-[zaam]ω	
b.	goud-ader	zuig-nap			
	lach-bui	strop-das		rib-fluweel	
	grijp-graag	rond-vaart		huis-vuil	

The morpheme *-achtig* is the suffix primarily motivating the class of compound-like suffixes in the language (Booij 1977): it is vowel-initial, fails to allow syllabification across the boundary, and triggers final devoicing in the preceding stem. Suffixes such as *-e* and *-en* occur inside ω’s by a number of similar phonological criteria: they trigger resyllabification and have no final devoicing before them, and there are no Dutch full words with schwa as their only vowel (Zonneveld 1983:310, Booij 1995:48). By the latter criterion the past tense suffix is also ω-internal (G & K’s examples presuppose this assumption, but it is left unmentioned). G & K tableaux for past tense examples look as below:

(37) a. Dutch past tense: voiceless (G & K 1998a)

/ [klap - de] ω /	AGREE	ID-ω-ONSET STOPLAR	ω-FINAL DEVOICING	IDSTEM LAR	IDLAR
klap - de	*!				
klab - te	*!			*	*
☞ klap - te					*
klab - de				*!	*

b. Dutch past tense: voiced (G & K 1998a)

/ [krab - de] ω /	AGREE	ID-ω-ONSET STOPLAR	ω-FINAL DEVOICING	IDSTEM LAR	IDLAR
krap - de	*!			*	*
krab - te	*!				*
krap - te				*!	*
☞ krab - de					

The IDSTEMLAR constraint is the central constraint of this past tense progressive assimilation analysis. It expresses the fact that for the feature mentioned "it is usually more important to be faithful to featural specifications in the root than to featural specifications in affixes" (G &K 1998a:26). A constraint family of this type was first suggested by McCarthy & Prince (1995:364ff.), who – using examples from Turkish, Sanskrit and Arabic – proposed that UG contain the metaconstraint ROOT-FAITH » AFFIX-FAITH (see Alderete 2003 for a recent in-depth example).

This account invites a number of comments; making a distinction between theoretically flavoured comments and empirical ones, let us deal with them in that order. First, the ID-ω-ONSET-STOPLAR constraint is claimed to be the result of the local conjunction described in (35c). But neither supplying constraint plays a role in the analysis, and no attempt is made to independently motivate them either. This considerably weakens the appeal to conjunction as the formal source of this, by G & K's own admission, "crucial" constraint, giving one essentially no reason to prefer it to, say, FRICDEV.[22] Second if, as the authors propose, all Lombardian constraints (except FRICDEV) will stay in the UG pool, then clearly there is a striking redundancy in the system: there are essentially two ways of dealing with final devoicing, to wit G & K's 'direct' way, and IDONSETLAR » *LAR » IDLAR, which is Lombardi's way (cf. (25a)).

The empirical problems are as follows. First, one of the most vexing questions of the Dutch past tense pattern, namely 'how to block syllable final devoicing', is left undiscussed. We know G & K have σ-FINAL DEVOICING next to ω-FINAL DEVOICING (cf. (35a), and recall cases like *me*[t]*ley* from (10)), but it is difficult to see how the σ-variant can function in the hierarchy. Clearly in order to account for *me*[t]*ley* it must precede ID(STEM)LAR, but the set-up of the past tense is such that IDSTEMLAR » σ-FINAL DEVOICING must hold, cf. (37b). The conclusion follows that the analysis simply fails to capture the Dutch past tense. Second, IDSTEMLAR

is empirically problematic in relatively run-of-the-mill cases of regressive assimilation involving ω-internal suffixes starting with an obstruent, to wit *-te, -sel, -ke* and *-ster* from (13) in the voiceless class, and *-de* in the voiced class. Consider the tableau below:

(38) voiceless obstruent-initial suffix (G & K 1998a prediction)

/ [hoog - te] ω / 'height'	AGREE	ID-ω-ONSET STOPLAR	ω-FINAL DEVOICING	IDSTEM LAR	IDLAR	(σ-FINAL DEVOICING)
hoox - de	*!			*	*	
hoog - te	*!				*	*
☞ hoog - de					*	*
☛ hoox - te				*!	*	

These suffixes contain schwa as their only vowel, so cannot be prosodic words. Notice that σ-FINAL DEVOICING (added separately in the tableau) could solve this problem if not for the interference of the past tense pattern just observed.

The past tense suffix can be directly opposed to a suffix of the same phonological shape, with the other suffix triggering *regressive* assimilation. Left unanalysed by G & K, this is the numeral suffix *-de* '-th', listed in (13a), and further illustrated below:

(39)	a.	sonorant-final numbers		fricative-final numbers		
		2: twee	twee-de	5: vijf	vijv-en	vij[v]-de
		3: drie	der-de	6: zes	zess-en	ze[z]-de
		4: vier	vier-de	11: elf	elv-en	el[v]-de
		7: zeven	zeven-de	12: twaalf	twaalv-en	twaal[v]-de
		9: negen	negen-de	20: twin-tig	twintig-en	twintig-ste
		10: tien	tien-de	100: honderd	honderd-en	honderd-ste
	b.	2^{10}: twee-tot-de-*tien*-de		5^{6}: vijf-tot-de-ze[z]-de (cf. *ze*[s])		
		3^{a}: drie-tot-de-*a*-de		8^{f}: acht tot-de-e[v]-de (cf. *f*= *e*[f])		
		4^{m}: drie-tot-de-*em*-de		10^{s}: tien tot-de-e[z]-de (cf. *s*=*e*[s])		
	c.	0: nul	nul-de	–6: min-zes	min-ze[z]-de	
		π: pi	pi-de	etc.		

(39a) shows that the suffix occurs after numbers below '20(th)', after which *–ste* takes over completely ('1st' is *eer-ste*; '8th' is *acht-ste*, possibly because the number ends in a plosive). These limited cases might be taken to indicate that this suffix is of very low productivity, and the marked case when compared to its sister
–ste and to fully productive past tense *–de*. However, although this is not commonly recognized, numeral *–de* is very productive, too. It is used in the 'to-the-power-of' construction with more than just numbers (39b), and in fact can be added to anything that strikes one's mathematical fancy, as long as this stem falls within its range (39c). Regressive assimilation occurs across-the-board. Thus, this

suffix is a clear counterexample to the G & K analysis, which claims that generally obstruent-initial ω-internal suffixes will undergo progressive assimilation; this claim is incorrect. In fact, the past tense suffix is the only suffix to do so.

7. *Another analysis in Optimality Theory (G&K II)*

The second G & K analysis of Dutch voicing (1998b, 2000) is partly similar to and partly different from the first. It is equivalent right up to the past tense, when a route is taken completely different from IDSTEMLAR. Consider the two new past tense tableaux below (ID-ω-ONSET STOPLAR and ω-FINAL DEVOICING omitted for reasons of space; these constraints are not violated by any of the candidates in (40):

(40) a. Dutch past tense: voiceless (G & K II)

/ [klap - de] ω /	AGREE	σ-FINAL DEVOICING	IDONSET LAR	*LAR	IDSTOP LAR	IDLAR
klap - de	*!			*		
klab - te	*!	*	*	*	**	*
☞ klap - te			*		*	*
klab - de		*		**	*!	*

b. Dutch past tense: voiced (G & K II)

/ [krab - de] ω /	AGREE	σ-FINAL DEVOICING	IDONSET LAR	*LAR	IDSTOP LAR	IDLAR
krap - de	*!			*		*
krab - te	*!	*	*	*	*	*
krap - te			*		**	*!
☞ krab - de		*		**		

Compared to G & K I, many more constraints are active in ‘the second half’ of the analysis, including IDONSETLAR and *LAR from Lombardi’s work, and ID-STOPLAR from G&K’s (35cii).

Three of the comments on the analysis of the previous section apply here, too: that on the conjunction underlying ID-ω-ONETSTOPLAR; that on the final devoicing redundancy; and the empirical comment about general regressive assimilation before obstruent-initial ω-internal suffixes. Granting that a striking visual difference between this analysis and the previous one resides in the dotted lines between some of the constraints, the apparent (because undisclosed) G&K interpretation of these lines is the following. For each candidate the total number of violations must be calculated for the entire block. In these examples this neutralizes the first constraint pair, and brings the second block into action: the same method there leads to the empirically correct result. That this calculation procedure is the correct interpretation of the authors’ intentions is confirmed by the way the exclamation marks indicate the point of a candidate’s failure. Such a ‘coranking’ of constraints (Inkelas 1999:183), however, has a standard interpretation in the litera-

ture which is different from G&K's (Kager 1999:404-407, McCarthy 2002a:26-28, 227): coranked constraints define grammars in which the constraints *are* mutually ranked, according to all logical possibilities. When two constraints happen to be irrelevant to one another, this is without consequence; when two constraints are in conflict, the two orderings will give different outputs. Then, according to a proposal originally due to unpublished work by Kiparsky (see Anttila 1997, McCarthy 2002a:227) the two orderings describe (optional) variation in the output in a given language. Returning to (40) and considering the block of unordered constraints comprising σ-FINALDEVOICING and IDONSETLAR, we see that neither situation holds: the constraints are not mutually irrelevant but they are in conflict; and the output does not vary but it is fixed.[23]

There is a passage in the OT literature, common to Tesar & Smolensky (1998:249-254) and Tesar & Smolensky (2000:47-50), in which a similar procedure is discussed under the name of the "stratified hierarchy". Stratified hierarchies are the result of language learning by the process of Constraint Demotion, by which constraints obtain lower and lower positions in the hierarchy when the child is stepwise trying to conform to the properties of the target language; demotion is to a lower 'stratum', the evaluation properties of which Tesar and Smolensky describe as in (41a) below. However, these authors also motivate the claim that an adult grammar (the endpoint of the acquisition process) always be a totally ranked hierarchy, cf. (41b):

(41) a. When C1 and C2 are in the same stratum, two marks *C1 and *C2 are equally weighted in the computation of Harmony. In effect, all constraints in a single stratum are collapsed, and treated as though they were a single constraint, for the purposes of determining the relative Harmony of candidates. Minimal violation with respect to a stratum is determined by the candidate incurring the smallest sum of violations assessed by all constraints in the stratum. (p. 241)

b. [T]he learning data are generated by a UG-allowed grammar, which [...] is a totally ranked hierarchy. When learning is successful, the learned stratified hierarchy, even if not totally ranked, is completely consistent with at least one total ranking. The empirical basis [for this claim] is the broad finding that correct typologies of adult hierarchies. Generally speaking, allowing constraints to have equal ranking produces empirically problematic constraint interactions.

From the learnability perspective, the formal results given for E[rror] D[riven] C[onstraint] D[emotion] depend critically on the assumption that the target language is given by a totally ranked hierarchy. (p. 249)

Thus, G & K's use of coranked constraints, or a stratified hierarchy, is at odds with existing proposals in the literature, and with Tesar and Smolensky's reasoned view of the 'endstate' of the process of first language acquisition.

Within G & K's second 'coranked' block in (40) two remarkable properties hold. First, the two Identity constraints have virtually identical evaluation results. In fact, the analysis would work equally well when it simply doubled IDLAR's marks. This is relevant because this is the only place in G & K where IDSTOPLAR (one of the two constraints underlying G & K's local conjunction towards ID-ω-ONSETSTOPLAR) is given a role, although it turns out that it serves to get the

arithmatic right by multiplying the IDLAR effect. Even more remarkably, two strictly ordered pairs out of the three constraints of this final block give exactly the same result as adding up marks, namely IDSTOPLAR » *LAR, or – more simply – IDLAR » *LAR. One suspects there must be a reason for not using one of these latter ordered pairs ('avoid ordering when adding up works', perhaps), but it is not disclosed by the authors.

8. *Revisiting -d-e (PT)*

The conclusions from the previous three sections taken together imply that no accurate OT account exists of the facts of Dutch voicing. It is the purpose of the final two sections of this paper to formulate such an account. The point of departure will be Lombardi's 1999 'skeletal' analysis of these facts (repeated here in (42) from (32)), in combination with the comments in (33) on the two areas of special interest: fricative devoicing and past tense progressive assimilation.

(42) = Basic Lombardi OT analysis of Dutch

/ hand - zaam /	AGREE	FRICDEV	IDONSLAR	*LAR	IDLAR
hant - zaam	*!	*		*	*
hand - saam	*!		*	*	*
hand - zaam		*!		**	*
☞ hant - saam			*		*

This analysis does not hinge on a difference between ω- and non-ω-affixation.[24] No stratified blocks appear in it, and it covers the Dutch facts up to the behaviour of the past tense suffix – albeit crudely so in so far as it incorporates the FRICDEV constraint whose "validity", (33) submits, "needs to be confirmed". The next section will deal with FRICDEV, essentially confirming that it is, as (33) also submits, "some constraint interaction effect". The current section deals with past tense assimilation. The discussion's premise is that this case's analysis cannot be fully phonological, because (a) regressive assimilation is the rule both universally and language-specifically, as opposed to progressive assimilation; and (b) the (productive) Dutch numeral suffix /-de/ shows re- rather than progressive assimilation. Given this, an approach such as the following can be envisaged.

It is a well-known observation about Dutch verbal morphology that the verbal 'stem' is phonologically surprisingly stable (Trommelen & Zonneveld 1979, Koefoed 1979, Kooij 1981, Zonneveld 1982), i.e. it exhibits 'paradigm uniformity'. Past tense progressive assimilation is just one manifestation of that notion, and in so far as it is wider, a constraint such as G & K's IDSTEMLARPT, although interpretable as a contribution to a formal representation of the idea, is only a small part of the story. In fact, Trommelen and Zonneveld's 'theme vowel' analysis discussed in section 3 can be seen as an attempt at covering the broader picture in one 'rule-based' sweep. These authors' 'independent evidence' for it alluded to in that section comprises the following:

(43) a. A (minor) rule of ‘open syllable lengthening’ creates alternations in nouns, but their related verbs have paradigm uniformity:
bad ~ *ba:den* ‘bath(s)’ vs. *ik ba:d* ~ *ba:den* ‘I/to take a bath’;

b. A rule of ‘*d*-weakening’ before an inflectional schwa creates alternations in adjectives, but verbs have paradigm uniformity:
goed ~ *goe[j]-e* ‘good’ vs. *bloed* ‘blood” ~ *ik bloe*[j] ~ *bloe*[j]-en ‘I/to bleed’;

c. Given schwa-deletion before another vowel, verb stems undergo it across the board:
elite ~ *elit-air* ‘elit(ist)’ vs. *sco:re* ‘score’ ~ *ik sco:r* ~ *sco:r(e)-en* ‘I/to score’;

d. Given word-final post-schwa *n*-deletion, verb stems fail to undergo it:
opə(n) ‘open, adj.’ vs. *ik opən* ~ *opəne(n)* ‘I/to open’;

e. Given a rule of ‘loss of final *j*’, verb stems have paradigm uniformity:
vlo ~ *vloo[j]-en* ‘flea(s)’ vs. *ik vloo[j]* ~ *vloo[j]-en* ‘I/to flea (one another)’

This survey shows that the syndrome is much larger than just stem preservation in past tense progressive assimilation. The stability manifests itself in two types: overapplication of a process (a-c), and underapplication (d-e). OT has a way of dealing with such patterns in the form of Output-Output Identity. OO-IDENT intends to cover those cases in which a (morphologically) derived form copies a phonological property (or properties) of a Base, which itself is an output (Kager 1999: Ch.6, McCarthy 1999:174-176). In (44a) below is an OO-IDENT pattern occurring in Icelandic deverbal action nouns (Benua 1995), involving – in derivational terms – truncation (of –*a*) when going from infinitive to derived noun; (44b) gives (in a slightly condensed version) the tableau of one example, adapted from Kager (1999:265ff.), in which the infinitive (output) form serves as the Base.

(44) a. Icelandic OO-IDENT pattern

klifra [v]	‘to climb’	~ klifr [v]	‘climbing’
kumra	‘to bleat’	~ kumr	‘bleating’
puukra	‘to conceal’	~ puukr	‘concealment’
siifra	‘to lament’	~ siiffr	‘lamentation’

whereas elsewhere: *[–son][+son]# and *VVCC

b.

/ sifr-a/ - [siifra]	DA-N =σ	OO-IDENTINF	SONORITY	*VOWEL LENGTH	IO-IDENT
☞ siifr		*	*	*	*
siif		**!			*
sifr		**!	*		*
s(i)ifr-a	*!				(*)

This closely resembles the Dutch situation. Adopting the infinitive as the Base for OO-IDENT in this language, too – this is the form in which the underlying voice

value surfaces – the constraint will be placed above IDONSETLAR in the hierarchy, to enforce progressive assimilation: AGREE » OO-IDINF » IDONSETLAR leads to [krab-de] from /krab-de/ (*krap-te) and [klap-te] from /klap-de/ (*klab-de). This seems intuitively promising, but unfortunately there is a serious snag: referring back to the data in (17), this proposal works for the past tense and the inflected past participle, where full progressive assimilation shows up; the uninflected past participle, however, undergoes neutralization (final devoicing), cf. *ge-kra*[p-t] from /ge-krab-d/ and *ge-kla*[p-t] from /ge-klap-d/, which violates paradigm uniformity. The subhierarchy of OO-IDINF » IDONSETLAR (»*LAR) fails to predict this: it is the correct hierarchy for progressive past tense assimilation, but *LAR » OO-IDINF is the one neutralization calls for. Dutch past tense paradoxes of this kind are by now familiar terrain, and a natural question to ask is whether there is a constraint or constraint interaction situation that will possibly improve upon this performance. The answer is yes, and involves local conjunction. Tableau (45) below gives the result of conjoining the two pivotal constraints relevant to the verbal cases under scrutiny, namely *LAR and OO-IDINF.

(45) Past tense progressive assimilation and neutralization by local conjunction (&); infinitive base: *krab* (-en) 'to scratch', *klap* (-en) 'to applaud'

		*LAR&OO-IDINF	IDONSLAR	*LAR	OO-IDINF
i. a. /krab-de/	☞ b-de			**	
	p-te		*!		*
b. /klap-de/	b-de	*!		**	*
	☞ p-te		*		
ii. a. ge-/krab-d/	b-d			*!*	
	☞ p-t				*
b. ge-/klap-d/	b-d	*!		**	*
	☞ p-t				
iii. a. ik /krab/	b			*!	
	☞ p				*
b. ik /klap/	b	*!		*	*
	☞ p				

The tableau shows just those candidates which survive AGREE. Among those cases in which the conjoined constraint results in a star, just that of (ib) is crucial: this is where progressive assimilation is enforced. The other two are straightforward cases of final devoicing, independently explained by IDONSETLAR » *LAR (» OO-IDINF).

It is so far not so clear from these progressive assimilation vs. neutralization cases why crucially the analysis is couched in terms of output-output rather than input-output identity (as in G & K's IDSTEM constraint). Both options seem to work equally well. This issue harks back to data mentioned as early as (11) of this

paper, which – translated into OT terms – now constitute a Richness of the Base argument. Some currently crucial cases are those of (46):

(46)	feest	'party'	feest-en	'to party'	fees(t)-te
	gesp	'clasp'	gesp-en	'to clasp'	gesp-te
	inkt	'ink'	inkt-en	'to roll ink'	ink(t)-te
	hoofd	'head'	ont-hoo[v-d]-en	'to behead'	onthoo[v(d)]-de
	fiets	'bicycle'	fiets-en	'to ride a bicycle'	fiets-te
	hypothetical *kiets*		*kie[d-z]-en		*kie[dz]-de

As pointed out above, this pattern implies that if a stem ends in an obstruent cluster, the cluster is underlyingly voiced only if it ends in a plosive; if it ends in a fricative, it will always be voiceless. By OT's assumption of Richness of the Base ("no language-particular restrictions on the input", cf. Prince & Smolensky 1993, McCarthy 2002a:70ff.), the constraints will have to explain the latter gap. It will follow from the analysis in the next section that this gap is predicted by FRICDEV » IDONSETLAR for the infinitive (*fiets-en*/**kiedz-en*) ('old' and 'new' FRICDEV do not differ here) but not for the past tense. This clearly suggests a role for output-output identity based on the infinitive, as shown in tableau (47).

(47) Hypothetical verb ending in a fricative-final cluster, past tense progressive assimilation; underlying form /kiedz/, inf. *kiet$s-en* by FRICDEV » IDONSETLAR

/kiedz-de/ ~ [kietsen]	*LAR&OO-IDINF	IDONSLAR	*LAR	OO-ID-INF	IO-ID /-STEM/
kiedz-de	*!		***	*	
☞ kiets-te		*			*

The tableau shows how *LAR conjunction based on output-output identity succeeds, where input-output identity fails. As in (45), the *Lar&OO-Id-Inf conjunction is not crucial to those forms of this hypothetical verb which are simply subject to final devoicing; they are therefore not shown.[25]

Thus, an empirically correct conjunction analysis exists for all cases of past tense assimilation and neutralization. It is nevertheless presented with some reservations. Its validity partly depends on considerations concerning 'metaconstraints' on local conjunction, touched upon in the next section when focusing on Dutch FRICDEV (in a proposed account of which conjunction again plays a vital role).

9. *Fricative Devoicing as (multiple) local conjunction*

The remaining empirical question of this paper concerns the Dutch fricative devoicing phenomenon. The proposal put forward here again uses conjunction as the core mechanism of the analysis. The constraints involved are well-known *LAR, and possibly less familiar *ONSETFRIC, banning fricatives from occurring in onsets. *LAR will first undergo self-conjunction, to derive a constraint called LYMAN'SLAW in recent work by Ito & Mester (1998, 2002, 2003) on Japanese. In

this language, interestingly, stems cannot contain more than one voiced obstruent, as shown by examples such as those in (48) (2002:33-36):

(48)	kaki	‘persimmon’	kagi	‘key’	gaki	‘kid’	*gagi
	toku	‘solve’	togu	‘sharpen’	buta	‘pig’	*buda

Ito and Mester’s proposal is to take out the co-occurrences of two voiced obstruents by a ‘self-conjoined’ version of *LAR.[26] The forms *kagi* and *gaki* violate this conjoined constraint once, but it is the double violation in *gagi* that represents “the worst of the worst” (McCarthy 2002a:18). LYMAN’SLAW therefore takes the following form:

(49) LYMAN’SLAW: No co-occurrence of voiced obstruency with itself (domain: the morpheme).

The current proposal is that the reason Dutch speakers reject **ron*[d-v]*aart* is closely related to why Japanese speakers reject **gagi*. Note that LYMAN’SLAW contains a domain statement, which cannot be the one relevant to Dutch. The Dutch domain is that of the obstruent cluster, which we know to be an independently recognized domain in the AGREE constraint (recall discussion in section 5).

*ONSETFRIC is first and foremost prominent in the literature on child speech. A survey of pre-OT child speech sources discussing phenomena motivating its existence can be found in Zonneveld (1999): Leopold (1947), Menn (1971), Gierut (1985), Chiat (1989), Fikkert (1994), and others. These phenomena include deletion (as in [is^y] for *fish*), stopping (as in [tua] for *Schuhe* ‘shoes’ in German), *h*-ization as in [hoχ] for *vork* ‘fork’ in Dutch), metathesis (as in [uz] for *zoo*, and [nouz] for *snow* in English), and so on. The constraint’s effects have been less frequently reported for adult languages, but it is not impossible to find potential cases of its applicability. Keren Rice (pers. comm.) suggests a case in Athapaskan by which $t + x \rightarrow k$: “a constraint like *FRICONSET could be used to choose the right manner of articulation. There are, of course, fricative onsets, but if there is a choice between a fricative and a stop, the stop will always prevail”. Roelandts (1962), citing Boyd-Bowman (1955), gives examples of Latin American Spanish hypocoristics such as those below involving fricative > *p*:

(50)	Bonifacio	> Pacho	Flora	>	Poya	Josefa	>	Pepa, Pita
	Delfina	> Pina	Francisco	>	Paco	Ofelia	>	Pela
	Felipe	> Pil	José	>	Pepe	Serafina	>	Pina

Based on just a small handful of data, the conclusion might be drawn that at some stage (Getxo) Basque treated loanwords from Spanish in a similar manner (Hualde & Bilbao 1992:3); informal sources suggest that Uyghur, too, treated borrowings from Arabic and Persian like this. A possible phonetic explanation underlying the constraint might be that the aperiodic sound source of fricatives is not very salient prevocalically, making at least plosives better onsets than fricatives.

Bernhardt & Stemberger (1998:432) offer the explanation that in addition to [–continuant] being a default value, fricatives can appear in codas earlier than in onsets because continuancy is preferred throughout rhymes, "grounded in the fact that vowels must be made with an open vowel tract". Another application can be found in Gnanadesikan (1995/2004), Pater (1997) and Pater & Barlow (2003), who propose the following 'fixed ranking' (in Pater's version) with the function of relating the 'sonority hierarchy' to syllable position:

(51) *GL-ONSET » *LIQ-ONSET » *NAS-ONSET » *FRIC-ONSET

Although fixed, this ranking can be interrupted in a given analysis by conflicting constraints. The ranking's constraint of current interest is the final one. Assuming that it is available from UG, tableau (52) shows how the fricative devoicing effect can be derived, when &-FRICDEV is the conjunction of LYMAN'SLAW and *ONSETFRIC:

(52) Fricative Devoicing as local conjunction

/ hand - zaam /	AGREE	&-FRICDEV	IDONSLAR	LYMAN'S LAW	*LAR	*ONSET FRIC
hand - saam	*!	*	*		*	*
hant - zaam	*!				*	*
hand - zaam		*!		*	**	*
☞ hant - saam			*			*

Comparing (42), tableau (52) implies a slightly different but still effective evaluation of the candidates. In the full Dutch hierarchy, &-FRICDEV is immediately followed by the usual constraints enforcing regressive assimilation and final devoicing, one of which is *LAR contributing to LYMAN'SLAW. Obviously, *ONSETFRIC will be (very) low-ranked because obviously Dutch has fricatives in onsets.

The proposed setup conforms to Lombardi's idea that generally apparent progressive assimilation ought to be due to the interference of high-ranked independent constraints. A number of constraints enforcing similar effects are much less plausibly invoked: conjoining simple *LAR rather than LYMAN'SLAW makes the incorrect prediction that Dutch has no initial voiced fricatives; *LARFRIC (Alderete 2003) cannot replace *ONSETFRIC because Dutch allows internal clusters such as [zb], cf. *huisbaas* (5a) and *asbest* (11a). On the other hand, the hierarchy in (51) adequately captures the skewed distribution of these latter examples' mirror image clusters: recall *fatsoen* ~ **fa*[dz]*oen* from (11a), and *fiets* ~ *fiets-en* ~ **fie*[dz]-*en* from (11b), also discussed in the previous section. Further empirical support will be presented immediately below. Notice also, though, that if *ONSETFRIC is accepted as a vital component of the proposals put forward here, this implies the addition of a constraint expressing 'positional markedness' into an analysis that relies on 'positional faithfulness' for the core voicing phenomena in natural languages (recall section 5). The introduction to this paper referred to Lombardi (2001) and Alderete (2003) (analysing Navajo) to the effect that such a

situation cannot and should not be excluded. Regarding multiple local conjunction resulting in &-FRICDEV, to demonstrate the beneficial effects of this mechanism is one of the aims of Ito & Mester's (2003) analysis of a variety of processes in German, and the analysis proposed here gratefully adopts this device. One of its attractive characteristics is that, pending further investigation, it appears to account well for the infrequency of the fricative devoicing pattern among the languages of the world: it is the cumulative effect of conjoining C1 and C2, where C1 is the result of self-conjunction. Embedded self-conjunction is probably not a frequent situation, and this may go some way towards curtailing potentially adverse factorial-typological implications.

A small handful of remarks wind up this discussion, some of them empirical, and some theoretical regarding 'metaconstraints' on conjunction as proposed in the recent OT literature. Because of the differences in how they assess candidates, &-FRICDEV is empirically more accurate than 'old' FRICDEV was, in two ways. The data in (53) concern Dutch assimilating clusters larger than two obstruents:

(53)	a.[27]	rups-band 'caterpillar track'	ru[bz-b]and	- by &-FD, * by OLD-FD
		rups-en (pl.)	*ru[ps-p]and	- by &-FD, √ by OLD-FD

- sim.: *aarts-dief* 'errant thief', *boks-beugel* 'knuckle dusters', *ex-dokter* 'former doctor', *fiets-band* 'bicycle tire', *flits-blokje* 'flash cube', *gips-beeld* 'plaster figure', *kaats-bal* 'rubber fives ball', *loods-dienst* 'pilotage', *rots-blok* 'boulder', *sex-bom* 'sex-bomb', etc.

	b.	hoofd-zaak 'essentials'	*hoo[vd-z]aak	* by &-FD, * by OLD-FD
		hoo[v]d-en (pl.)	hoo[ft-s]aak	√ by &-FD, √ by OLD-FD

- sim.: *jeugd-vriend* 'friend from way back', *deugd-zaam* 'virtuous', *smaragd-groen* 'emerald green', etc.

The cases of interest are those in (53a) in which regressive assimilation and fricative devoicing partly overlap, the former prevailing. Old FRICDEV makes an incorrect prediction here. &-FRICDEV passes the choice on, simply because there is no violating onset fricative; then, IDONSETLAR will make the correct choice (cf. (52)), routinely selecting regressive assimilation.

Next, the data in (54) contain obstruent clusters in *onsets*, not present in any of the examples discussed so far, unless by accident.

(54) a.	stal	'stables'	studie	'studies'	straat	'street'
	stoom	'steam'	station	'station'	streek	'region'
	spin	'spider'	spektakel	'spectacle'	spraak	'speech'
	spoor	'trace'	specerij	'spice'	splijten	'to split'
	ski	'ski'	score	'score'	sclerose	'sclerosis'
	schaar	'scissors'	schommel	'swing'	schrijven	'to write'
	sfeer	'atmosphere'	sfynx	'sphynx'	sfincter	'sphincter'

b.	tsaar	‘czar’	tseetsee	‘tsetse fly’	tsunami	‘tsunami’
	psalm	‘psalm’	psyche	‘psyche’	psoriasis	‘psoriasis’
	xenon	‘xenon’	xylofoon	‘xylophone’	Xantippe	‘Xantippe’
c.	ftisis	‘phthisis’	ftaal	‘naphthalene’	Pfeiffer ‘glandular fever’	
d.	ptyalase	‘ptyalin’	pterosaurus	‘pterosaur’		
	Ptolemaeus	‘Ptolemy’				

These examples are just a handful of members of the large class of obstruent cluster-initial words in which the peripheral obstruent is (virtually always) *s*-. Generally speaking, a Dutch complex onset has a ‘Germanic’ shape: roughly Obstruent(-Liquid), optionally preceded by an *s*- (Trommelen 1983, Fikkert 1998). Once the peripheral element is recognized to be a fricative, a prediction is derived within the current framework: since the onsets violate *ONSETFRIC, they will automatically be voiceless, by AGREE and &-FRICDEV. This is exactly right: onset obstruent clusters are voiceless in Dutch.[28] In other (previous) frameworks this is often a separate ‘morpheme structure’ condition (Zonneveld 1983, 1994), here it simply follows from the analysis. Also observe that FRICDEV does not predict this pattern, since in most cases the fricative is not in right-edge cluster position. Each step down in (54) implies lower frequency/familiarity for the cluster type involved. The data in (54b) have non-peripheral *s*, those in (54c) have *f*. The analysis correctly predicts voicelessness. In (54d) a different area is entered, namely the prediction that full-plosive clusters will generally be ‘faithful’ (giving voice a chance to surface) *vis-à-vis* actual native speaker behaviour. Differently from English, where cluster reduction seems a strongly preferred strategy, Dutch speakers apply consonant-faith and often insert a schwa-like element into the cluster: [pətesosáurus]. This process has wider application, generally affecting any ‘difficult’ cluster in loans: G[ə]dansk, G[ə]staad, T[ə]blisi, N[ə]guyen, [ə]Ng[œ], [ɛ]Mbeki, [ə]Ndour, and so on.[29]

Following Lombardi, the current analysis avoids sanctioning (forms of) final devoicing formulated as ‘positional markedness’. While PM is proposed to coexist with PF, it should be noted that PM FINDEV (or *CODAVOICE) is suspect not just because of the G & K redundancy noted in section 6. Lombardi (2001) observes that languages shunning final voiced obstruents have a priorily available a number of different strategies: devoicing the obstruents, but also deleting them, or resyllabifying them by inserting a final vowel. Interestingly, languages never seem to employ the latter two strategies. If this is true, this is – she submits – an inexplicable factorial-typological gap under the assumption that FINDEV is a UG constraint, because the absent strategies could be triggered by a high ranking of FINDEV » FAITH. The empirical gap is explained, however, by her core constraint set (section 4 of this paper) when IDLAR is replaced with MAXLAR, in itself a theoretically interesting move (briefly: given /pid/, universally a candidate [pidi]

is always a fatal violation of *LAR and 'no insertion', and [pi] always one of MAXLAR and 'no deletion').

"Lombardi's conundrum" (McCarthy 2002b:286) just outlined underlies the PF approach towards Dutch voicing adopted in this paper. At the same time, however, Ito & Mester (1998, 2002, 2003) use FINDEV in a way that suggests that stopping it from appearing in grammars may be easier said than done: they propose that FINDEV be the conjoined offspring of the two independently motivated UG constraints *CODA and *LAR. In response, Fukazawa & Lombardi (2003) try to develop proper criteria (metaconstraints) for local conjunction. One of their suggestions is that the conjunction of a structural constraint (*CODA) and a markedness constraint (*LAR) be prohibited, banning FINDEV. In fact, the strong version of their proposal is "that only constraints from the same constraint family can be adjoined" (p. 204). Obviously, in the current context self-conjoined LYMAN'S LAW falls within the range of this proposal, as does the conjunction of LYMAN'S LAW and *ONSETFRIC: these are all members of the family of markedness constraints. The conjunction analysis of the Dutch past tense falls outside it, involving as it does a markedness constraint and an (OO-) faithfulness constraint. However, Fukazawa & Lombardi (2003:206) cite a number of recent Markedness & Faithfulness conjunction cases as potential counterexamples to their own claim (Łubowicz 2002, Ito & Mester 2003). It does not seem very farfetched, therefore, to assume that for a reason currently less than perfectly understood Markedness & Faithfulness conjunction is allowed, but Markedness & Structure prohibited. If so, this paper can be taken to show that both the Dutch past tense progressive assimilation and the fricative devoicing phenomenon are cases of (or follow from) the conjunctions of independently motivated UG constraints.

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Notes
1. This notion of historical sketch should not be confused with that of the vademecum. The purposes of this contribution are as just stated. The author is aware that Dutch voicing phenomena have been, and could be further, analysed in a variety of frameworks left undiscussed here. Since the study of [voice] is in no small measure a typological one, properties of voicing in other languages than Dutch will bear on the proposed account. To show that, and the extent to which, this is so, is a matter of ongoing research. Published references to other languages that immediately bear on the discussion have been included in this paper (most often in the footnotes), but also here full coverage was not the aim and cannot be guaranteed.

2. Phonetic symbols are used here when Dutch spelling needs clarification; see Booij (1995) and Heemskerk & Zonneveld (2000) for rules of Dutch spelling-pronunciation correspondence. (Note that geminate consonants are a spelling convention, indicating that the preceding vowel is lax – the consonants are always pronounced as singletons. Among the letters for velar obstruents *ch* = [χ]

(*lach* below), g = [ɣ] initially (*grijp* below) and medially (*zorgen*) but [χ] finally (*zorg*); *g* stands for [ɡ] in recent loans from a variety of languages, such as *angstgegner, baguette, gangster, goulash, hooligan, jungle, reggae, gig*. See also fn. 3.

3. Initial *g* (= [ɡ]) in loans (see fn. 2) is not usually included in surveys like this, because compounds containing such loans as members sound slightly artificial; yet, for this author examples like *top/nep-gangster* [b-ɡ] 'top/mock gangster', and *proef-gig* [v-ɡ] 'try-out gig', seem to gladly follow the prediction suggested by their place in the system.

4. The properties of the Dutch voicing rule set were given as an example of the 'Duke of York gambit' in Pullum (1976), i.e. the rules sometimes derive an output identical to the input through a different intermediate stage: X>Y>X, see e.g. /bloed-bank/ in (7). Whether such derivations must be avoided or not has since been a point of debate. Pullum (p. 100) came to the conclusion that "a thorough investigation [...] does not reveal any basis for a general constraint that would prohibit" the gambit. More recently, claiming the undesirability of a gambit analysis, Halle & Idsardi (1997:344-345) analysed the English 'intrusive r' phenomenon using a version of the Elsewhere Condition as a blocking device on rule application. This issue will briefly return below.

5. Some of the literature (Booij 1995, Grijzenhout and Krämer) discusses the voice behaviour of 'clitics' (articles, some adverbs, special forms of personal pronouns). The position taken here is that this is an underresearched area, about which most claims are premature. As just one example, consider Booij's case of [von$t-ik] 'found-I' (next to *vond-en* 'found, PL'), which he analyses as a case of opaque rule interaction, in which FINDEV unexpectedly precedes syllabification. For many speakers this form is accompanied by voiced mirror images such as [la$d-ik] 'leave-I' and [mu$d-ik] 'must-I', from *lat-en* 'to leave' and *moet-en* 'must' – suggesting that the issue is more complex. See Zonneveld (1982) for some related unexpected patterns involving 'clitic voice'.

6. It would not have been unreasonable to include the diminutive suffix *–(t)je* in this list, but it is omitted because of its complex allomorphy, cf. Trommelen (1983).

7. *-de* is the singular inflection form; the plural takes an additional *-n*: *(ge-)noem-de-n*, etc.

8. Ernestus & Baayen (2003) discuss an experiment using nonsense verb stems which in the present singular end in a voiceless obstruent, in which native speakers produce assimilated past tenses which "reflect correlations between final rhymes of [verb stems] and the underlying [voice] specification of the final obstruents" as existing in a large database. Thus, for instance, nonsense *kijns* gives 30% *kijns-te* (70% *kijns-de*), whereas *taars* gives 76% *taars-te* (24% *taars-de*). Intriguing as they may be, these results are not followed-up upon here.

9. An implicit assumption of the analysis is that renewed syllabification follows a relevant rule such as theme vowel deletion.

10. Below, for brevity's sake the Laryngeal node will only be included when relevant.

11. This is possible even in P & P, assuming for instance a distinction such as that between 'core' and 'periphery' as in Piggott (1988), following Chomsky (1982) (but then see Chomsky cited in Strozer 1994:159).

12. Wetzels and Mascaró's (2001) paper contains an elaborate and critical discussion of Lombardi's work. Among other things, they argue for a binary, i.e. non-privative, feature [±voice], on the basis of languages in which [–voice] appears to be active, such as Dutch (but see immediately below), Yorkshire English, Parisian French, and Bakairi and Ya:the, both indigenous languages of Brazil. Literature making the same point includes Rubach (1996) on Polish, Inkelas, Orgun & Zoll (1997) on Turkish, and Krämer (2000) on Ile de Groix Breton.

Lombardi (1996) reviews some of the then available cases, and concludes that the privative [voice] hypothesis holds at the lexical level because (p. 32) "[a]ll of the rules that require negative values of these features pass the test for being postlexical rules". From this point of view, the interest of the Dutch patterns resides in the interaction between lexical and postlexical patterns, mixed with the additional ingredient of real or apparent progressive assimilation.

Iverson & Salmons (2003) argue that the examples put forward by Wetzels and Mascaró lend themselves to privative reanalyses using a more sophisticated set of laryngeal features, following Halle & Stevens (1971), and Avery & Idsardi's (2001) 'dimension theory' of the laryngeal articulator. Their account of Dutch is a straightforward translation of Lombardi's P & P analysis into their framework; their proposal on the past tense will be briefly discussed below.

13. Or possibly a morphologically conditioned parameter-setting, a situation not unheard of in phonology, compare in metrical phonology English extrametricality being conditioned by the noun-verb distinction, see Hayes (1982).

14. See e.g. Mohanan (1991) vs. Inkelas, Orgun & Zoll (1997).

15. The authors make a point of claiming (p.13) that Fricative Devoicing is not "progressive assimilation ... at all" but "post-obstruent fricative neutralization"; they overlook the fact that the possibility of this view has been around in accounts of Dutch voice at least since Trommelen & Zonneveld (1979) and Zonneveld (1983) (cf. (3a) of this paper), and was adopted by Lombardi (1991).

16. Ralph (1973) may be seen as a very early precursor of this approach.

17. English may have extrametrical consonants for reasons of word stress, again see Hayes (1982).

18. Lombardi (1999:287) observes that in this typology Swedish has "the only known pattern that requires IDLAR to be ranked above IDONSETLAR". For comments on this point and further details of Swedish, see Helgason & Ringen (ms.), and Petrova et al. (ms.). The latter paper also discusses Russian, Hungarian and German. Other papers addressing the languages and/or some of the major tenets of Lombardi's work are, for instance: Brockhaus (1995) on German, Rubach (1996) on Polish, Iverson & Salmons (1999) on English and German, Wetzels & Mascaró (2001) on Yiddish and Polish, and Jessen & Ringen (2002) on German. In-depth analyses of laryngeal phenomena in Athapaskan (Navajo) can be found in Rice (1994) and Alderete (2003).

19. The evaluation adheres to Lombardi's proposal (1999:295-297) that IDLAR assess configurations rather than the properties of single segments; it therefore assigns just a single mark to a violation, as in the case of **dok-s* in tableau (30b).

20. Harms is also claimed to be active in Polish onsets (where the mirror image situation to that of English obtains), cf. Lombardi (1995:59-64).

Replying to a referee's comment, Lombardi (1995:62) acknowledges that this constraint mentions "voiceless" and – given current understanding – would be "difficult to state without [–voice]" (also see Mohanan 1991:314). She adds, however, that such a formulation would be "totally unexplanatory": it is not a problem introduced by the hypothesis of privative [voice], but seems "to fall into a class of deeper problems for phonological theory".

21. The other examples are: Yiddish with only one suffix, Polish [r], Athapaskan in cases of a "prefix-stem boundary only", and "progressive devoicing of voiced obstruent-initial suffixes" in Turkish.

22. Technically, ID-ω-ONSETSTOPLAR cannot be the conjunction of the two proposed supplying constraints because desired output *han*[t-s]*aam* for underlying *han/d-z/aam* is precisely the candidate violating both constraints, the conjunction of which then rejects rather than selects it. Presumably, the proposed conjunction should be made active just in the domain of the onset.

23. A striking difference between G & K (1998b) and (2000) is the absence from the latter paper of the first 'coranked' block. This is empirically feasible because in the authors' view the constraints cancel one another out, but it is infelicitous because it is the task of this block to explain 'how final devoicing is blocked in the past tense'; this issue now remains unaddressed in the only regularly published version of G & K's analyses.

24. This is not to deny that these domains can be relevant to other phonological areas of Dutch, such as the syllabification behaviour of the suffix *–achtig* discussed in section 5.

25. McCarthy (1999:385) proposes OO-IDENT, using the devoiced sg. past tense [vont] as the Base, as a solution to the [von$t-ik] clitic case of fn. 5; the comments in the second half of the latter footnote remain applicable, however.

26. Similarly, Alderete (1997) applies ‘self-conjunction’ to the phenomenon of dissimilation; also see further cases in Pater (2001) and discussion in McCarthy (2002a:18-19, 43).

27. Voicing harmony seems harder to determine in these long clusters, but one indication is that assimilation and degemination occur when the final two consonants differ just in voice, *ka*[z-d]*eur* being ambiguous between *kas-deur* ‘greenhouse door’ and *kast-deur* ‘cupboard door’, *rij*[z-d]*iner* between *reis-diner* ‘travel dinner’ and *rijst-diner* ‘rice dinner’, and *so*[v-d]*rugs* between *sof-drugs* ‘failed drugs’ and *soft-drugs*.

28. Recall that we are working with ‘resyllabified’ structure, at which stricter ‘earlier-level’ syllable structure is no longer applicable, so *s*- is not ‘extrasyllabic’ any longer; to this extent the analysis relies on an as yet to be developed OT theory of Dutch syllable structure.

29. Cluster reduction is sometimes found, however, and also weakening of one of the members. Cf. *Dvorak* [(d)vórak], *Danzig* (as an alternative to *Gdansk*), [ʒ]*on* for English *John*, [dj]*azz* for *jazz*, a spelling pronunciation such as [j]*ack* for *jack* ‘jacket’ (similarly [j]*errycan*, [j]*umper*), *S*[w]*erdlowsk*, and so on. The treatment of such words in Dutch is certainly an area worth further investigation. For comments on similar clusters in English see Iverson & Salmons (1999), Davidson (2003), and Davidson et al. (2004); for German, see Wetzels & Mascaró (2001:215).

Wetzels & Mascaró (2001:211) also claim that “word-initial clusters are always non-derived in Dutch”. Taken literally this is incorrect, although the existing examples are certainly less than fully impressive. Pairs like *dom* ‘ignorant/*stom* ‘stupid’, *duwen* ‘to push’/*stuwen* ‘to force’, numeral *–de/ste* (section 5), and a small handful of others (Zonneveld 1983:309), may illustrate a rare and certainly unproductive *s*-prefix, confirming the current analysis. A discontinuous temporal affix (deriving adverbs from nouns) appears in a limited number of cases such as *s-maandag-s* ‘on Monday’, and *s-ochtend-s* ‘in the morning’; initial *s*- is left unexpressed before obstruents, but curiously leaves ‘fricative devoicing’ as a trace: *dinsdag-s* ‘on Tuesday’ vs. *vrijdag*/[f]*rijdag-s* ‘on Friday’. (In Optimality Theory this invites involving Sympathy, cf. McCarthy’s 1999:331-337 similar case in Tiberian Hebrew.) A discontinuous numeral affix appears in *t-ach(t)-tig* ‘80’; initial *t*- is left unexpressed before consonants, but leaves ‘fricative devoicing’ as a trace: *negen-tig* ‘ninety’ vs. *zeven*/[s]*even-tig* ‘seventy’ (Van Loey/Schönfeld 1959:153). The relevance of these cases will depend on one’s desire to include or not such unproductive examples in an analysis of Modern Dutch. (Although especially the second affix may have been productive at a relatively recent stage, in combination with active fricative devoicing.)

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Representations of [Voice]
Evidence from Acquisition

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We consider two theories of laryngeal representation, one using a single feature [voice] generalizing across prevoicing languages and aspiration languages, and the other using multiple features: [voice] for pre-voicing languages and [spread glottis] for aspiration languages. We derive predictions for children's early productions, and test these for three Germanic languages. Children acquiring Dutch, a prevoicing language, show de-voicing of stops, while available data from German, an aspiration language, show de-aspiration. Although the difference might simply reflect intrinsic properties of children's early production and perception systems, we argue that a representational account is in order, based on multiples features. The case is made for English, an aspiration language, based on the early productions of a single child. A laryngeal harmony pattern is found which spreads voicelessness from coda to onset, which is argued to involve activity of [spread glottis]. This is interpreted as evidence for a laryngeal representation involving multiple features.

1. *Introduction*

A great deal of recent research has addressed the representation of laryngeal features (Avery 1996, Avery & Idsardi 2001, Iverson & Salmons 1995, 2003, Jessen 1989, 1996, Jessen & Ringen 2002, Lombardi 1991, 1995, 1999, 2001, Salmons & Iverson 2003, Steriade 1995, 1997, Van Rooy & Wissing 2001, Vaux 1998, Wetzels & Mascaró 2001). Debates in the literature focus on several major aspects of phonological theory, including monovalent versus bivalent features, gradient versus categorical processes, and phonetic detail in phonological representation. In discussions of these issues, evidence from a range of sources has been used, including phonetics, phonology, typology, and diachrony. Surprisingly, very little evidence from acquisition has been brought to bear on the issue of laryngeal representation.

Acquiring the laryngeal phonology of a language amounts to identifying the relevant contrasts, building up a representation of laryngeal features, and learning to produce these contrasts in an adult-like fashion. By studying children's developing language systems, we can gain insight into how laryngeal features are represented. Acquisition patterns provide a way to test claims about the representations of laryngeal features. This paper presents corpus analyses of the acquisition

of initial obstruents in Dutch and German, and the acquisition of initial and final obstruents in English. Children's productions of voiced and voiceless obstruents were analysed for realizations of laryngeal features. These analyses revealed a number of interesting error patterns.

First, productions of children acquiring Dutch, which is a so-called prevoicing language, differ from productions of children acquiring German and English, which are aspiration languages. Production errors of children learning Dutch tend to favour voiceless stops in initial position, whereas children learning German (Grijzenhout & Joppen-Hellwig 2002) and English (Menn 1971, Smith 1973) exhibit the opposite error pattern, producing more voiced stops. This confirms earlier results from acquisition studies of prevoicing languages such as Spanish and Hindi (Macken & Barton 1980b, Davis 1995) and of aspiration languages such as English and German (Macken & Barton 1980a).

Second, the frequency of voicing in children's targets that children attempt to produce does not reflect the error patterns related to voicing. For example, while production errors of young children acquiring Dutch show a trend toward initial voiceless stops (/b/ → [p] and /d/ → [t]), a statistical analysis of children's targets reveals rather the reverse trend: children attempt more voiced than voiceless word-initial stops. This finding implies that children's error patterns reflect factors other than frequency of targets in children's productions, such as articulatory factors or featural representation.

Lastly, children's voicing errors in English turn out to be conditioned by the laryngeal specification of segments occurring later in the word; more specifically, the devoicing of initial stops is triggered by a following voiceless obstruent. However, no 'harmonic' effect is found for the voicing of initial obstruents when followed by voiced obstruents.

These acquisition data were used to test different theories' claims of how laryngeal features should be represented in languages that display a two-way laryngeal contrast: either with a single binary feature [±voice] (Wetzels & Mascaró 2001), or multiple language-dependent features, specifically monovalent [voice] and [spread glottis] (Iverson & Salmons 1995).[1] Results from this study will be argued to support Iverson & Salmons' theory, in which aspiration languages (including English and German) use the feature [spread glottis], while prevoicing languages (including Dutch) use [voice].

Importantly, our study supports a multiple feature view, under which languages use one constant active feature to represent their laryngeal contrasts in all positions, initial and final. The harmony pattern observed in English acquisition data supports this view: interaction between initial and final obstruents implies a shared monovalent featural representation for voicing in these positions, which abstracts from specific phonetic realization. A purely phonetic account cannot readily account for this pattern.

This paper is organized as follows. Section 2 will discuss the major theories of laryngeal representation to be considered, stating predictions they make for error patterns in children's productions in English, Dutch and German. In section 3, we will discuss Dutch acquisition data, which we will compare with German data in

section 4. Then we will find that children acquiring Dutch, a prevoicing language, produce errors involving devoicing of stops that are voiced in the target word, whereas the available German data show rather the reverse pattern, in which consonants that are voiceless in target words are produced as ‘voiced’ or more accurately, as plain unaspirated stops. In comparing the acquisition data from Dutch, a prevoicing language, and German, an aspiration language, two major interpretations will be considered: a phonetic one, based on intrinsic properties of children’s early production and perception systems, and a phonological one, based on the Multiple Feature Hypothesis. In section 5, these hypotheses will be tested on English, using a corpus-based study of the early productions of a single child, whose laryngeal error patterns will be discussed in detail. We will argue that error patterns involve the activity of [spread glottis] in a laryngeal harmony pattern affecting only voiceless consonants in coda and onset of a word. This will be interpreted as evidence for a representation of laryngeal contrasts involving multiple features, [voice] (for prevoicing languages) and [spread glottis] (for aspiration languages). Finally, we will discuss consequences of our findings in section 6.

2. *Theories of laryngeal representation*

2.1 *One versus multiple features*

The phonetic realization of laryngeal contrasts[2] varies across languages. The main acoustic cue associated with voicing is voice onset time or VOT, which refers to the time between a segment’s release and the beginning of vocal cord vibration. There are a number of ways in which laryngeal contrasts are realized in languages (Cho & Ladefoged 1999). In the languages studied in this paper, a two-way contrast is employed. However, there are also languages that employ a six-way contrast, as for example Beja (Cushitic) and Igbo (Kwa) (Ladefoged 1973, cited in Iverson & Salmons 1995:382). For the purpose of this paper, however, it is important to note the VOT differences in stops[3] across Dutch, German and English. These values (based on Lisker & Abramson 1964, Braunschweiler 1997) are given in Table 1.

	Voicing Lead	Short Lag VOT	Long Lag VOT
Dutch	-80 ms: b, d	0-25 ms: p, t	
German		16 ms: b, d	51 ms: p, t
English		32 ms: b, d	59 ms: p, t

Table 1: *VOT in Dutch, German and English*

The laryngeal contrasts in these three languages can be divided into those that exhibit voicing lead (where voicing begins before the release), short lag VOT (where voicing begins at the time of the release or shortly afterwards), and long lag VOT (where there is a delay between the release and the beginning of voicing). In languages such as Dutch, the contrast in initial position is one between voicing lead and short lag VOT, while in aspiration languages such as German,

the initial contrast is one between short lag and long lag VOT (where long lag VOT results in voiceless aspirated stops). Similar to Dutch are languages such as French and Spanish. Similar to German are English and most other Germanic languages (except Dutch and Germanic languages such as Afrikaans, Frisian, and Yiddish).

The question then naturally arises as to whether the featural representations of prevoicing and aspiration languages are different. There are two primary views in the literature. The standard approach within current phonological theories assumes that a single feature captures the laryngeal contrasts of all languages with a binary contrast, generalizing across prevoicing languages and aspiration languages. This single feature is either a binary feature [±voice] (Steriade 1995, Wetzels & Mascaró 2001), or monovalent [voice] (Mester & Ito 1989, Cho 1990, Lombardi 1995, 1996). For the purposes of this paper, we refer to these theoretical variants as the Single Feature Hypothesis. Laryngeal specifications for Dutch, German and English for both variants are given in Tables 2 and 3.

	Voicing Lead	Short Lag VOT	Long Lag VOT
Dutch	[+voice]	[–voice]	
German		[+voice]	[–voice]
English		[+voice]	[–voice]

Table 2: *Laryngeal feature representation for Dutch, German and English under the Single Feature Hypothesis, using a binary feature [±voice]*

	Voicing Lead	Short Lag VOT	Long Lag VOT
Dutch	[voice]	[ ]	
German		[voice]	[ ]
English		[voice]	[ ]

Table 3: *Laryngeal feature representation for Dutch, German and English under the Single Feature Hypothesis, using a monovalent feature [voice]*

Note that the laryngeal contrasts of Dutch, German and English are captured with the same distinction between [+voice] and [–voice] (or [+voice] and [ ]), but the acoustic correlates for these features differ for Dutch versus German and English.

A second approach to laryngeal features was advanced by Jessen (1989, 1996) and Iverson & Salmons (1995, 2003), who argue that laryngeal features are best represented with multiple monovalent features such as [voice] and [spread glottis]. In languages with a binary laryngeal contrast, only one of these (the active feature) is underlyingly specified. A language's selection of laryngeal feature can be diagnosed by its active phonological processes, and it tends to correlate with VOT properties of stops. This approach will be referred to as the Multiple Feature Hypothesis since it assumes two monovalent features, [voice] and [spread glottis].[4] According to Iverson & Salmons, prevoicing languages, such as Dutch, represent the laryngeal contrast by a monovalent feature [voice], such that voiced

stops are specified and voiceless stops are unspecified. Aspiration languages, such as German and English, select the active feature [spread glottis], such that aspirated stops (voiceless) are specified, and unaspirated stops (voiced or voiceless) lack specification, indicated by [ ]. The laryngeal specifications under this approach for Dutch, German and English are given in Table 4.

	Voicing Lead	Short Lag VOT	Long Lag VOT
Dutch	[voice]	[ ]	
German		[ ]	[spread glottis]
English		[ ]	[spread glottis]

Table 4: *Laryngeal feature representation for Dutch, German and English under the Multiple Feature Hypothesis, [voice] and [spread glottis]*

Under the Multiple Feature Hypothesis, the Dutch voicing contrast is expressed by representing pre-voiced stops with the feature [voice], while voiceless segments lack specification in their phonological representation. Aspiration languages such as German and English represent their laryngeal contrast with [spread glottis] on aspirated stops, and lack of specification on plain (unaspirated voiceless) stops. Note that both [voice] and [spread glottis] are abstract phonological features in the sense that their phonetic realizations vary and depend on the position in the word. For example, [spread glottis] is realized with maximal aspiration (i.e. fully abducted vocal folds) only in the onset of foot-initial syllables, while other positions have weaker implementations (Iverson & Salmons 1995:377).

Having sketched the Single Feature Hypothesis and the Multiple Feature Hypothesis, we are now in a position to turn to acquisition, which provides a testing ground for theories of laryngeal feature representation.

2.2 *Acquisition of laryngeal contrasts: Previous studies*

Previous studies on the acquisition of voicing have found developmental differences between prevoicing and aspiration languages. With respect to the time course of acquisition, it appears that laryngeal contrasts are acquired later in prevoicing languages than in aspiration languages (Macken & Barton 1980a,b, Davis 1995). While the Dutch contrast is acquired some time around the age of three (Kuipers 1993a,b, Beers 1995), the English contrast is acquired relatively early, by the age of two (Macken & Barton 1980a). Previous research (Davis 1995) has indicated a role of acoustic salience in these acquisition differences, where prevoicing (voicing lead) is argued to be less salient than aspiration (long lag VOT). This suggests that some of the acquisition differences seen in languages are to some extent attributable to ease of perception and, possibly, production. However, differences in acoustic salience across languages do not exclude the possibility that differences in acquisition are due to different feature representations across languages. This paper will explore the phonetic versus phonological accounts for the patterns seen in acquisition.

2.3 *Further assumptions and predictions*

The accuracy of children's productions can be taken to reflect children's phonological knowledge and representations. Children's production errors have been argued to reflect innate universal grammar (Jakobson 1941/1968 and others), given that children's production errors can often be characterized as neutralizing to the unmarked value. For example, children often delete final consonants and produce CV syllables, e.g., *taart* /taːrt/ 'cake' is produced as [taː] in Dutch (Fikkert 1994), *Tag* /tag/ 'day' as [d̥aː] in German (Kerstin 1;5, see below), and *tape* /teyp/ as [tʰeː] in English (Seth 1;7, see below). These production errors can be interpreted as reflecting phonological knowledge, such as the knowledge that the universally preferred syllable shape is a CV syllable. It is a well-known observation (Jakobson 1941/1968) that criteria for markedness based on cross-linguistic evidence are supported by language acquisition, as children tend to produce the least marked properties before more marked ones (cf. Zamuner 2003, Zamuner, Gerken & Hammond 2005). Returning to the example of syllable structure, we note that children initially produce the least marked CV syllables, before producing more marked syllable shapes, such as those with final consonants (Fikkert 1994, Levelt et al. 2000).

Assuming Jakobson's hypothesis that children's initial errors reflect the unmarked values of phonological features, we can derive a number of predictions regarding children's error patterns, based on the Single Feature Hypothesis and the Multiple Feature Hypothesis. These predictions are given in Table 5.

	Representation	Unmarked	Error Type
Single Feature Hypothesis	[±voice] or	[–voice]	[+voice] → [–voice]
	[voice]	[ ]	[voice] → [ ]
Multiple Feature Hypothesis	[voice] (prevoicing languages)	[ ]	[voice] → [ ]
	[spread glottis] (aspiration languages)	[ ]	[spread glottis] → [ ]

Table 5: *Predictions of the acquisition of laryngeal features based on the Single Feature Hypothesis and Multiple Feature Hypothesis*

Recall that the Single Feature Hypothesis makes use of a single binary feature of [±voice] or monovalent feature [voice]. The unmarked value for this theory is invariant across languages, because all languages utilize the same feature to represent laryngeal contrasts. With a binary feature, this unmarked value is [–voice]. If children's initial productions tend toward the unmarked value, this would predict that the direction of errors is cross-linguistically uniform, and should be independent of the language that children are acquiring. Accordingly, children learning Dutch, German or English are all predicted to make devoicing errors [+voice]

→ [–voice]. These errors would affect words starting with (marked) [+voice] consonants, while words starting with (unmarked) [–voice] consonants should not be affected. (For a monovalent feature, predictions are essentially the same, although the specifications are slightly different.) In contrast, the Multiple Feature Hypothesis would predict differences between prevoicing and aspiration languages regarding the types of consonants that are affected. Languages with prevoicing should display devoicing errors [voice] → [ ] (omission of the feature [voice]) in words starting with (marked) voiced consonants, while words starting with (unmarked) [ ] voiceless consonants should not be affected, whereas children acquiring aspiration languages should produce de-aspiration errors [spread glottis] → [ ] (omission of the feature [spread glottis]) in words starting with (marked) aspirated consonants, while words starting with (unmarked) unaspirated consonants should not be affected. In Table 6, the predictions are spelled out in terms of phonetic symbols.

	Dutch	German	English
Single Feature Hypothesis	/b/ → [p]	/b/ → [p^h]	/b/ → [p^h]
Multiple Feature Hypothesis	/b/ → [p]	/p^h/→ [p]	/p^h/→ [p]

Table 6: *Predictions of laryngeal errors for Dutch German and English, based on the Single Feature Hypothesis and Multiple Feature Hypothesis*

In sum, using Jakobson's hypothesis that children's errors are changes in the direction of the unmarked, theories of laryngeal representation make different predictions about consonants which are prone to undergo errors in acquisition. Hence, the acquisition of Dutch versus German and English provides an excellent test case for these theories.

3. *Dutch*

To test the predictions of the Single and Multiple Feature hypotheses, we collected acquisition data from Dutch, German, and English. Different corpora from the CHILDES database were studied. We will start with a discussion of the Dutch data, which were taken from the CLPF database (Fikkert 1994, Levelt 1994). The data from 11 Dutch monolingual children whose ages range between 1;0 and 2;11 were studied; this involved approximately 20,000 utterances. Examples of voicing errors are below.

(1) Examples of laryngeal errors in Robin's utterances

a.	douche	'shower'	[tus]	(1;10.21)
b.	dier	'animal'	[tiɹ]	(1;10.21)
c.	beer	'bear'	[pi]	(1;7.13)
d.	bal	'ball'	[pɑl]	(1;7.13)
e.	baby	'baby'	[pipi]	(1;8.10)
f.	thuis	'home'	[dœys]	(1;5.10)

(2) Examples of laryngeal errors in Tom's utterances

a.	boot	'boat'	[pɔ]	(1;5.0)
b.	bal	'ball'	[pɑ]	(1;5.14)
c.	bed	'bed'	[pɛt]	(1;5.28)
d.	doen	'do'	[tun]	(2;1.14)
e.	paard	'horse'	[bat]	(1;3.24)

Only productions of initial stops /b/, /p/, /d/ and /t/ were considered. These stops had to be faithfully realized for place of articulation to be included in our analyses. Dutch lacks the voicing contrast in velars; hence we did not consider the velar stop /k/. Also, fricatives were not included, because in many Dutch regions the distinction between voiced and voiceless fricatives is disappearing (Slis & van Heugten 1989, Ernestus 2000, Van de Velde et al. 1996, Van de Velde & van Hout 2001).

Not all children were monitored for the same period of time: Figure 1 shows the ages of the different children in the database. Note that at the beginning and end of the age span, data were collected for only one or two children: Tom at 1;0, Leon at 2;9 and Noortje at 3;0.

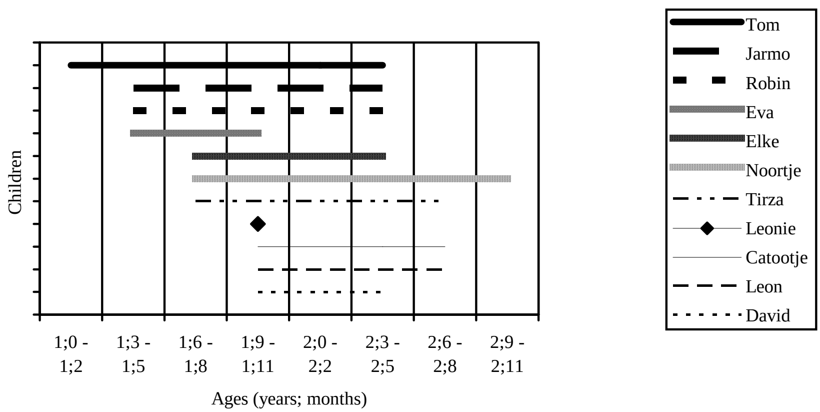


Figure 1: *Breakdown of children's ages from the CLPF database*

In Figure 2, the number of target words is given for each child. Note that the number of tokens is given here: for types, a similar pattern was found. In the remainder of the discussion of Dutch, we will only present results from token analyses. Figure 2 shows that all children attempted more voiced targets (/b/ and /d/-initial words, a total of 4871 targets) than voiceless targets (/p/ and /t/-initial words, a total of 2244 targets). On the basis of this, one might predict that children will be more accurate when producing voiced targets than when producing voiceless targets, but we will see that we find the opposite pattern: overall, children produced more voiceless than voiced stops.

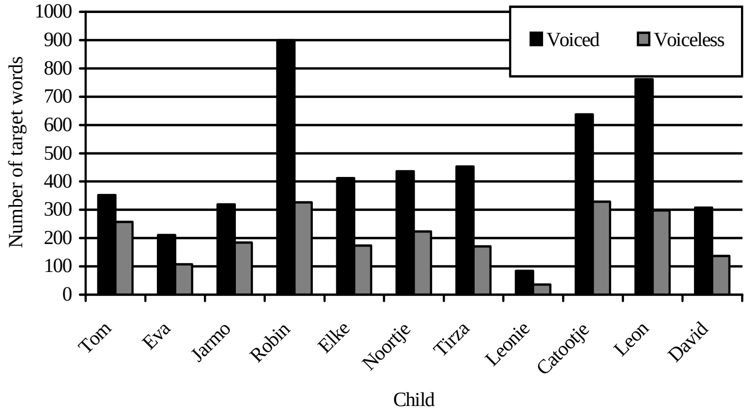


Figure 2: *Number of target words (in tokens) per child*

Figure 3 shows the error percentages of all children when producing word-initial stops. These percentages were determined by averaging the percentage error rate across children.

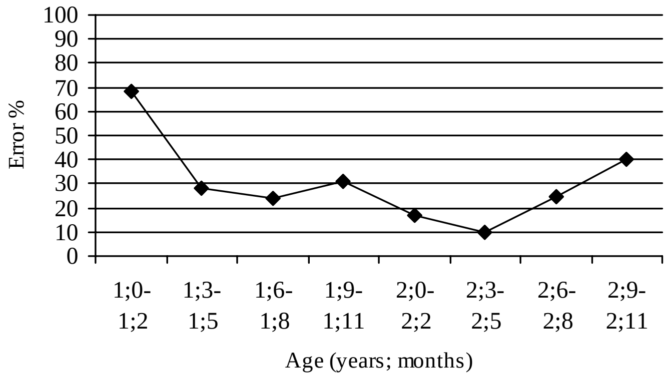


Figure 3: *Error percentages of all children*

In Figure 3, all errors children made in the voicing value of word initial segments are shown. Thus it collapses errors made both in voiced and voiceless segments. Children's productions become more faithful during the time they were studied. Apparently, the overall development curve is U-shaped, but this appearance is caused by the fact that at the age periods 1;0, 2;9 and 3;0 there are only data from one or two children. Noortje, who is the single child providing data at 3;0, was found to be late in her overall phonological development (Fikkert 1994). Hence, she causes a rise of the curve at this point. Her error rate for the production of initial stops remains quite high during the entire period in which she was studied.

When errors are broken down by place of articulation, we see that this factor does not play any crucial role in the production of the voice value. In Figure 4, the errors are broken down for labial-initial words (/b/ and /p/) versus alveolar-initial words (/d/ and /t/). There is no significant difference (*t-test*, $p = 0.11$, two-tailed) between the error rates of these two places of articulation, hence, we find no evidence that voicing in labials is either more or less difficult than voicing in alveolars.

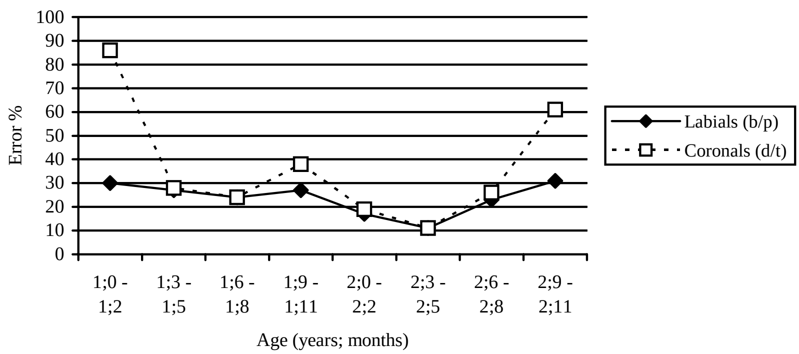


Figure 4: *Percentage of errors in coronal and labials*

In Figure 5, error rates are split for voicing errors (e.g., /p/ and /t/ produced as /b/ and /d/) and devoicing errors (e.g., /b/ and /d/ produced as /p/ and /t/). This clearly shows that there were more devoicing errors (M=42.75, SD=22.6) than voicing errors (M=9.25, SD=11.01). This difference is significant (*t-test*, $p \leq 0.01$, two-tailed), and holds for every stage. For all children, we see that devoicing errors persist well into the third year, while the rate of voicing errors drops to almost 0%.

We can also examine the extent to which Dutch children's initial 'voicing' production patterns reflect the distribution of voicing in the input (van der Feest 2004, 2007). For this analysis, we analyzed child-directed speech from the van de Weijer corpus (van de Weijer 1998). This corpus contains speech directed to a child between the ages of 2;6 and 2;9 (a selection of 18 days appears in the corpus). We conducted (type and token) counts of initial voiced and voiceless stops for different places of articulation. Results are summarized in Table 7.

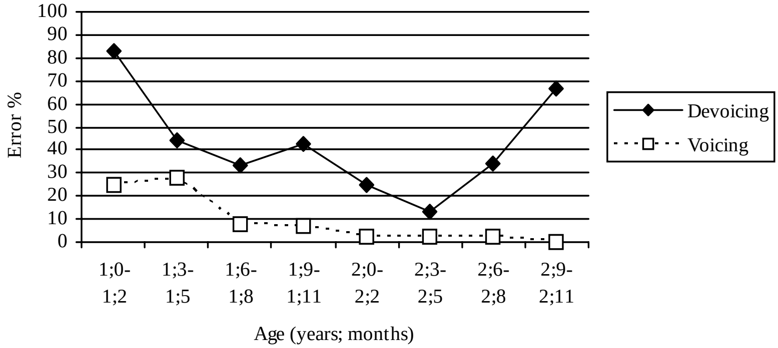


Figure 5: *Percentage of voicing and devoicing errors*

	Labials				Alveolars			
	p		b		t		d	
types	151	(40.7%)	220	(59.3%)	104	(41.3%)	148	(58.7%)
tokens	1492	(30.9%)	3342	(69.1%)	1481	(13.6%)	9389	(86.4%)

Table 7: *Distribution of voicing in child-directed speech from van de Weijer corpus*

There is a preference for voiced stops in both type and token counts in child-directed speech. This means that the errors patterns seen in Dutch production data (voiceless stops are produced before voiced stops) cannot be accounted for by input frequencies.[5]

To summarize these data, we can say that overall, Dutch children acquire the voicing system quite late, having not yet completed it by the age of 2;6. We have seen that for the acquisition of the Dutch voicing contrast, there is no significant effect of place of articulation. Also, although more target words have voiced onsets, children make more errors in voiced than in voiceless initial segments, while their overall productions contain more voiceless than voiced segments. These findings support the featural specification [voice] for Dutch, assuming that unmarked voiceless segments are acquired before the marked voiced segments.

However, the acquisition data from Dutch are consistent with both the Single Feature Hypothesis and the Multiple Feature Hypothesis. Under the latter hypothesis, voiceless segments are assumed to be unspecified for the monovalent feature [voice], and hence, predicted to be acquired before specified voiced segments, while under the former hypothesis (assuming a single binary feature [±voice]), voiceless segments would also be predicted to be acquired first. Here, voiceless segments are specified as [–voice], and would be less marked than voiced segments, which are specified as [+voice]. Since predictions from these hypotheses are identical, Dutch acquisition data could, in principle, never produce

any crucial evidence deciding between these hypotheses. It is important, though, that the acquisition patterns cannot be explained on the basis of input frequency.

Still, the two approaches predict different orders of acquisition for the German segments. The Multiple Feature Hypothesis, which assumes that aspiration languages such as German represent the laryngeal contrast by [spread glottis], would predict that voiced segments are acquired first, since these are unspecified for [spread glottis], and hence unmarked. The Single Feature Hypothesis, on the other hand, assumes voiceless segments to be universally specified as [–voice], and for that reason would predict such (unmarked) segments to be acquired first. We now turn to a discussion of German to see which of the two approaches is supported by our acquisition data.

4. *German*

German is an aspiration language, which differs from prevoicing languages such as Dutch in encoding its two-way laryngeal contrast by aspiration versus non-aspiration, at least in word onset position. As pointed out above, the Multiple Feature Hypothesis represents the German laryngeal contrast as one of [spread glottis] for aspirated /pʰ/, versus [ ] for plain /b̥/ (Jessen 1996, Jessen & Ringen 2002). Accordingly, the prediction from this hypothesis is that the production errors of children acquiring German will be predominantly of the /pʰ/ → [b̥] (or 'lenition') type, matching a neutralization of the feature [spread glottis]. Phonetically, such errors would amount to a failure to realize aspiration on a stop that is lexically specified as [spread glottis].

German data were collected from the Nijmegen Database in CHILDES (MacWhinney 1999).[6] We considered data from the only child in the database for which sufficient phonetic transcription was available, Kerstin (aged 1;3–3;4). From this large longitudinal database (containing approximately 25,000 utterances) we selected Kerstin's productions between ages 1;0 and 2;2, which allowed us to track her development with respect to laryngeal specifications.

Some characteristic examples of Kerstin's de-aspiration errors are given below:

(3) Examples of 'voicing' errors in Kerstin's utterances

a.	Papa	'daddy'	baba (1;5.7, 1;6.20, 1;7.24, 1;10.3, 1;11.20, 2;0.5)
b.	Puppe	'doll'	bibbaa (1;3.22), bubbaa (1;3.22)
c.	Tag	'day'	daa (1;5.3)
d.	Teddy	'Teddy'	diddie (1;5.6), dide (1;6.13), didi (1;7.24, 1;8.22)
e.	Turm	'tower'	dum (2;3.1)

Note that the informal transcription indicated in the corpus of items such as *Papa* as 'baba' and *Tag* as 'daa' suggests pre-voicing, rather than just de-aspiration. This was presumably due to a language-specific bias on the part of the transcribers, who may have perceived unaspirated stops as lenis stops /b, d/. We will interpret the transcriptions conservatively as evidence for de-aspiration only. In comparison, only a very small number of errors in the opposite direction was found.

The single clear example is *Becher* (1;5.17) transcribed in the corpus as ‘peschel’, presumably phonetically [pʰɛʃəl]. The near complete absence of initial devoicing/aspiration in Kerstin’s utterances contrasts with the situation in English, as we will see in section 6.

Quantitative analysis confirms that Kerstin’s errors are almost exclusively of the ‘voicing’ type: an unaspirated realization of stops corresponding to aspirated stops in the adult language. See Figure 6.

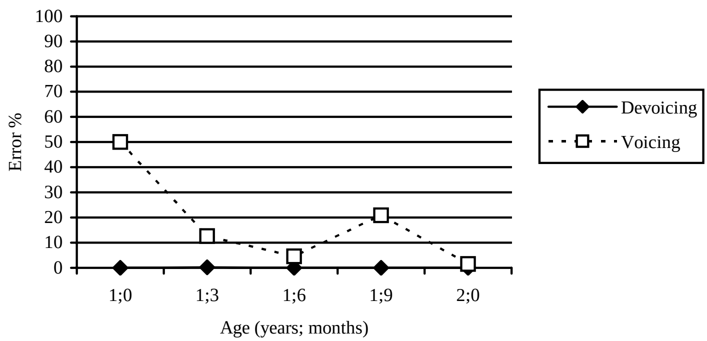


Figure 6: *Onset voicing versus devoicing in Kerstin’s errors*

Errors of the ‘devoicing’ type were extremely rare, while ‘voicing’ errors are abundant. This matches earlier observations for German acquisition (Grijzenhout & Joppen-Hellwig 2002). The prediction of the Multiple Feature Hypothesis is thus borne out.

To what extent does Kerstin’s initial ‘voicing’ pattern reflect the statistics of the input? We carried out an analysis of child-directed speech in the same CHILDES corpus, based on utterances from caretakers present during recording sessions in the relevant periods (Kerstin’s age 1;0–1;12). We conducted (type and token) counts of initial voiced and voiceless stops for different places of articulation. Results are summarized in Table 8.

	Labials		Alveolars		Velars	
	p	b	t	d	k	g
types	32 (28.57%)	80 (71.43%)	52 (37.14%)	88 (62.86%)	94 (45.63%)	112 (54.37%)
tokens	121 (20.9%)	458 (79.1%)	157 (6.24%)	2361 (93.76%)	638 (48.55%)	676 (51.45%)

Table 8: *Distribution of voicing in child-directed speech from Kerstin's corpus*

There is a noticeable trend toward voiced initial stops (especially for labials) in child-directed speech during Kerstin’s second year.[7] Kerstin’s error pattern is thus

compatible with the input she received. But although Kerstin's input matches the direction of her errors, input statistics alone cannot account for the error pattern. This is because Kerstin produced virtually no errors of the devoicing type during her second year, a much stronger result than might be expected on the basis of the input pattern alone.

In sum, the error pattern of a German child between ages 1;0 and 2;3, showing abundant voicing errors in initial stops, but hardly any devoicing errors, is naturally accounted for by the Multiple Feature Hypothesis as omission of the active feature [spread glottis], but not by the Single Feature Hypothesis, while an input-based account offers only a partial explanation.

5. *Interpretation and further predictions*

Summarizing so far, we found that the acquisition of the initial voicing contrast in Dutch is rather slow, and completed beyond the age of 2;6. Errors are predominantly of the 'devoicing' type. For German, the initial contrast is acquired earlier, and seems completed by the age of 2;0. Errors are overwhelmingly of the 'voicing' type (presumably, lenition or de-aspiration).

Two plausible interpretations of these findings suggest themselves, one phonological and the other phonetic. A strongly phonological account, which we have been assuming thus far, seeks a featural basis for the observed developmental differences. On the assumption that errors in early productions target the unmarked feature value, findings for Dutch and German would favour the Multiple Feature Hypothesis over the Single Feature Hypothesis, since only the former predicts differences in error patterns between the languages. The Multiple Feature Hypothesis models the Dutch voicing contrast on a monovalent feature [voice], and hence would correctly predict production errors of Dutch children to result in featurally unspecified stops, which are phonetically interpreted as 'voiceless'. The German laryngeal contrast, as opposed to Dutch, is based on a monovalent feature [spread glottis], which predicts German children's production errors to favour unspecified stops, phonetically realized as 'unaspirated' (that is, lenis and voiceless). The Single Feature Hypothesis, on the other hand, represents both languages by a single feature [voice], and hence would not predict any differences in the directionality of laryngeal errors between German and Dutch developmental patterns, as both languages would represent their contrasts by a single feature. (Note that, as indicated in Table 6, differences may occur between phonetic errors patterns in voicing and aspiration languages due to the language-particular implementation of the specifications [voice] and [   ].)

However, an alternative articulatory interpretation might be proposed, which would explain differences in error patterns between the languages, and hence would leave no room for testing the two representational hypotheses discussed above. According to what we will refer to as the 'Articulatory Effort Hypothesis', young children's initial preference for short lag VOT (that is, unaspirated voiceless stops) is due to lack of articulatory skills necessary to produce stops with either long lag VOT (aspiration) or short lead VOT (prevoicing). This would correctly predict that early German productions show a lack of aspiration, while early Dutch productions show a lack of prevoicing. To account for the developmental

differences between German and Dutch (i.e., age of acquisition of the contrast), the additional assumption would be needed that prevoicing is more difficult to produce than aspiration (Kewley-Port & Preston 1974, van Alphen, this volume). Alternatively, a perceptual account may be given following Davis (1995) and others: on the basis of greater perceptual salience of long lag VOT as compared to short lead VOT, children acquire the laryngeal contrast in aspiration languages earlier than in prevoicing languages.

The Articulatory Effort Hypothesis explains properties of children's errors in relation to the target language, but its validity need not rule out a role of featural representations in the explanation of error patterns. We are thus facing the following question: when considering children's laryngeal errors, how to distinguish effects of articulatory effort from effects of feature specifications? Here is an attempt to tease the two kinds of effects apart.

The Articulatory Effort Hypothesis would predict that errors correlate with the overall motoric complexity of a target. As is well-known, the articulatory effort required for the realization of a gesture may also depend on its position in an utterance. For example, it is much easier to maintain voicing in intervocalic contexts than in word-initial or final contexts. However, motoric effort should be independent of the presence of a target elsewhere in the utterance, specifically when they are not adjacent (for example, when two consonants are separated by a vowel), or when the targets are articulatorily diverse. Cross-linguistically, the articulatory gestures for laryngeal contrasts and the acoustic cues are quite varied. Cues include VOT, closure duration, duration of the preceding vowel (Keating 1984). Within a language, choice of laryngeal gesture may depend on a segment's position in the word, in the syllable, or on neighbouring segments. For example, English realizes laryngeal contrasts in onset mainly by VOT, and laryngeal contrasts in coda mainly by duration of the preceding vowel, closure duration, or glottalization. In sum, the Articulatory Effort Hypothesis would predict few interactions in error patterns between articulatorily heterogeneous positions, such as the onset and coda in English.

In contrast, a phonological account would predict contrastive specifications to appear in children's error patterns, which abstracts from fine-grained phonetic realization depending on position. For example, a phonological account would predict cases of 'laryngeal harmony' between onset and coda, in which only contrastive features would harmonize, not redundant ones.[8] (Cross-linguistic studies on laryngeal cooccurrence patterns include MacEachern 1997, Hansson 2001, Rose & Walker 2001.) It should be emphasized that by 'harmony' we generally refer to any kind of interaction between segments which produces identical contrastive feature specifications, without implying autosegmental spreading resulting in doubly-linked features. As Fikkert & Levelt (2002) argue, consonant harmony at early stages of development may be driven by a general requirement for stops to be featurally similar, regardless of whether similarity is achieved by spreading, by default, or by phonologically active features.

Radical underspecification of contrastive features would make an additional prediction that production errors reflect activity of the specified feature only, to the exclusion of the unspecified value. Under the Multiple Feature Hypothesis,

laryngeal features are monovalent, mainly to capture the observation that voiceless unaspirates are unmarked both in prevoicing and in aspiration languages. Languages differ as to which feature is specified: [voice] in prevoicing languages such as Dutch, and [spread glottis] in aspiration languages such as English. Underspecification thus creates predictions about harmony, since only unspecified segments should be the targets, assimilating non-locally to specified segments.

Different harmony effects would be predicted to occur, depending on the two featural approaches under comparison. Consonant harmony of place of articulation in children's early productions is typically anticipatory (Menn 1971, Smith 1973, Pater & Werle 2001, 2003, Fikkert & Levelt 2002), which leads us to expect a similar asymmetry for laryngeal harmony. For this reason, we will consider predictions for a hypothetical anticipatory harmony pattern, in which laryngeal errors in the onset anticipate the coda's specification.

Under a Single Feature Hypothesis with a binary feature [±voice], symmetrical error patterns within a language would be predicted, since both values are active, and potentially induce errors. This would predict a pattern with both devoicing and voicing in onsets, depending on whichever feature value is specified in the coda.

(4) Harmonies predicted by the Single Feature Hypothesis [±voice]

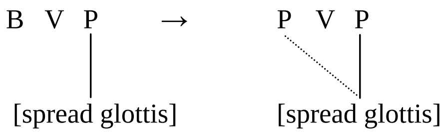
a. P V B → B V B
[+voice] [+voice]

b. B V P → P V P
[–voice] [–voice]

Note that a variant of the Single Feature Hypothesis based on a monovalent feature [voice] would only predict harmony of the type (4a), not (4b). Thus, if anticipatory laryngeal harmony were to be found in children's English, this could only be /PVB/ → [BVB]. This makes a strong prediction, which allows a rather straightforward test of these two versions of the Single Feature Hypothesis.

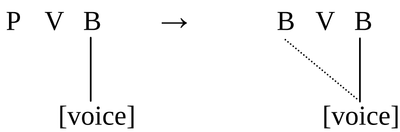
The Multiple Feature Hypothesis predicts patterns to be asymmetrical, and to correlate with a language's 'active' feature, either [voice] or [spread glottis]. That is, languages whose specified feature is [spread glottis] would be predicted to display only one kind of error: onset devoicing triggered by a voiceless coda /BVP/ → [PVP], but not onset voicing triggered by a voiced coda /PVB/ → [BVB], because voiced codas would be laryngeally unspecified [ ].

(5) Harmony predicted by the Multiple Feature Hypothesis: aspiration languages



Under the Multiple Feature Hypothesis, prevoicing languages should only display harmonies involving voiced segments, /PVB/ → [BVB]:

(6) Harmony predicted by the Multiple Feature Hypothesis: prevoicing languages



Note that the Multiple Feature Hypothesis and the monovalent version of the Single Feature Hypothesis make similar predictions for prevoicing languages. Predictions differ between the ‘monovalent’ frameworks, however, for aspiration languages. If the Multiple Feature Hypothesis is correct, English uses monovalent [spread glottis], and hence should display anticipatory harmony of the ‘devoicing’ type /BVP/ → [PVP], whereas if the Single Feature Hypothesis is correct, anticipatory harmony should be of the ‘voicing’ type, /PVB/ → [BVB].

In sum, to compare predictions made by the Single Feature Hypothesis and Multiple Feature Hypothesis, we must distinguish monovalent and binary variants of the latter. If children’s productions were to contain systematic patterns of voicing harmony, but not devoicing harmony, this pattern would be compatible with both the Multiple Feature Hypothesis and the monovalent version of the Single Feature Hypothesis, but it would form evidence against its binary version. Next, if harmony of the voicing and devoicing type were to systematically co-occur in a child’s productions, this would support the binary version of the Single Feature Hypothesis, but form evidence against both monovalent accounts. Finally, if we were to find that children’s production errors consistently display devoicing harmony, while lacking voicing harmony, this asymmetrical pattern would favour the Multiple Feature Hypothesis, but constitute evidence against the monovalent and binary variants of the Single Feature Hypothesis. The logical options are summarized in Table 9:

	Voicing harmony only	Both voicing and devoicing harmony	Devoicing harmony only
SFH, binary [±voice]	contra (circumstantial)	pro	contra (circumstantial)
SFH, monovalent [voice]	pro	contra	contra
MFH [voice] or [sg]	pro	contra	pro

Table 9: *Evidential status of hypothetical harmony patterns for the Single Feature Hypothesis (binary and monovalent) and Multiple Feature Hypothesis*

Let us now turn to a test case for the Multiple Feature Hypothesis against the Single Feature Hypothesis: English.

6. *English*

English acquisition data may serve as a test case, since this language precisely meets the conditions under which harmonic anticipations of laryngeal features might occur. First, English matches German (but not Dutch) in being an aspiration language. Hence, under the Multiple Feature Hypothesis [spread glottis] is specified, predicting this feature to be active in children's early phonologies. Indeed, English-learning children display de-aspiration errors (Menn 1971). Second, unlike German, English lacks syllable-final laryngeal neutralization, so that coda obstruents are specified contrastively. Since onsets and codas both license laryngeal specification, harmony effects become potentially visible. This meets the logical requirement which must be fulfilled for testing for positional interactions involving [spread glottis].[9]

6.1 *Earlier studies*

Earlier studies (such as Smith 1973) provide evidence for initial voicing and final devoicing in children's productions. Let us first turn to some data from Smith (1973). During the first half of his third year (ages 2;2–2;6), Amahl realized most of his initial stops as plain (voiceless unaspirated), by a general neutralization of initial laryngeal contrasts. In this period, initial neutralization affects voiced targets (for example, *bell*), as well as voiceless ones (for example, *pen*). (We adopt Smith's transcription.)

(7) Initial stops realized as voiceless unaspirated, irrespective of targets (ages 2;2–2;6)
  a. bell [b̥ɛ] (2;2)
  b. pen [b̥ɛn] (2;2)

In the same period, Amahl also neutralized most word-final stops to voiceless. Since this has audible consequences only for voiced targets (e.g. [mɔb̥] for *knob*), the overall effect is one of final devoicing.

(8) Final stops realized as voiceless (unaspirated), irrespective of targets
(ages 2;2–2;5)
a. knob [mɔb̥] (2;2)
b. stop [d̥ɔp] (2;2)

Amahl's development during this period is shown in Figure 7. The error percentages were calculated as the proportion of target words of which the laryngeal realization, [p], [b̥], or [b], deviated from the target specification, /p/ or /b/.[10] For target /b/, for example, any realizations deviating from it, either [p] or [b̥], were considered as devoicing errors.

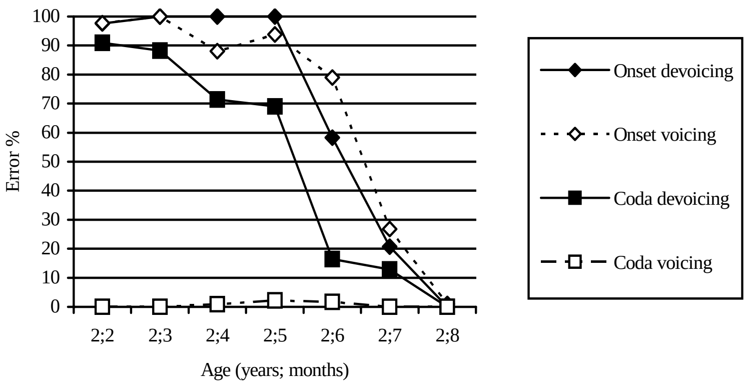


Figure 7: *Amahl's development (2;2–2;8)*

Note that the final contrast is acquired slightly earlier than the initial contrast, by about a month. The error rate of final devoicing drops sharply round age 2;5, while that of initial neutralization (as shown in the two topmost lines) follows at the distance of about a month.

The observation that Amahl's laryngeal contrast stabilizes slightly earlier in final than in initial position may come as a surprise, given that the child is unlikely to receive input with the laryngeal distinction directly realized on the final stop, whereas initial stops have robust VOT cues.[11] However, other cases are known of children acquiring English who mastered the laryngeal distinction in codas before it emerged in onsets (Clark & Bowerman 1986:55, fn. 5, Vihman & Ferguson 1987:383, Fey & Gandour 1982, but see Stoel-Gammon & Buder 1999). More generally, other consonant types, such as fricatives and liquids, are more likely to be first acquired in final position (Ferguson 1978, Stoel-Gammon 1985).

At best, we can offer speculative accounts of the coda-onset lag in Amahl's laryngeal development, as no acoustic data are available for verification. One ac-

count would attribute the lag to production factors rather than lexical representation; Amahl may have mastered control over vowel duration, the primary realization of laryngeal contrast in coda, before the gestural coordination between release and voice onset which is required for aspiration. Under this scenario, lexical representations in onset and coda are stable at an earlier stage, setting the stage for rapid across-the-board changes once the relevant gestures are mastered. Indeed, Amahl shows a rapid development of the laryngeal contrast in onset and coda, both of which are completed within approximately three months. Nevertheless, an explanation of the coda-onset lag based on developing lexical representations cannot be ruled out, because laryngeal error rates vary somewhat between individual lexical items, an observation which is difficult to explain under a production-only account. For example, during period 10-11 (at the age of 2;6) all three occurrences of *bread* had neutralized onsets, while all three occurrences of *Braj* (a name) were realized correctly. Hence, it is quite possible that Amahl's laryngeal contrast was lexically represented in final position before it emerged in initial position.

Relative strength of the laryngeal contrast in coda position will become a major factor in our central case study, to which we turn next.

6.2 *Seth: a case study*

The data in this section were taken from a large CHILDES database (Wilson & Peters 1988), containing approximately 12,500 utterances, with a total number of 39,000 words. All data were from a single monolingual child, named Seth, aged between 1;7–4;1, who was acquiring American English. Utterances in the database are matched with target words in plain orthography, and are phonetically transcribed at a level allowing for qualitative and quantitative analysis of voicing patterns. The original sound files were kindly made available to us in digitized form by Ann Peters and Brian MacWhinney for further transcription and acoustic analysis.

We monitored Seth's development between ages 1;7 and 2;5, the period during which major changes in the laryngeal contrast took place, and at the end of which Seth's productions of the contrast were largely indistinguishable from adults.

6.2.1 *Initial devoicing.* We first focused on word-initial position and collected all of Seth's productions of content word[12] targets containing an initial voiced or voiceless stop. This allowed us to search for factors which possibly influenced the proportion of two major types of error: initial 'voicings' (actually, de-aspirations resulting in plain stops) and initial 'devoicings' (actually, aspirations). The resulting dataset contained 227 types and 4354 tokens. Table 10 shows type and token distributions of initial voiced and voiceless target stops, for different places of articulation.

	Labials		Alveolars		Velars		Total
	p	b	t	d	k	g	
types	34 (37.78%)	56 (62.22%)	45 (63.38%)	26 (36.62%)	48 (72.73%)	18 (27.27%)	227
tokens	902 (58.95%)	628 (41.05%)	689 (42.98%)	914 (57.02%)	553 (45.29%)	668 (54.71%)	4354

Table 10: *Distribution of initial stop targets in Seth's productions (types & tokens)*

A representative set of examples of initial errors in Seth's early utterances are given below:

(9) Initial devoicing in Seth's utterances

Labials				Alveolars			
a.	bark	[paːk]	1;8	e.	Dabee	[tabij]	1;7
b.	boy	[paj]	1;9	f.	doughnut	[townaː]	2;0
c.	bike	[pajk]	1;10	g.	dog	[tagij]	2;2
d.	backpack	[pəkpək]	1;11	h.	drink	[trunk]	2;5

Velars

i.	geese	[kijs]	1;8
j.	go	[ko]	1;8
k.	got it	[kaːɾit]	2;2
l.	get	[ket]	2;3

(10) Initial voicing in Seth's utterances

	Labials				Alveolars		
a.	penny	[bənij]	1;11	e.	tape	[dejp]	1;9
b.	play	[bwedjʌ]	1;11	f.	trunk	[drʌŋk]	1;10
c.	peanut butter	[bi bʌdʌ]	1;11	g.	tan	[dən]	2;0
d.	play	[bejdl]	2;1	h.	tell	[dəʌ]	2;0

	Velars		
i.	kiss it	[giset]	1;8
j.	kitchen	[gisʌŋ]	1;9
k.	cookie	[gukij]	1;10
l.	cool	[guw]	1;10

Although both types of initial errors are abundant, Seth makes more devoicing errors than voicing errors in initial position, as shown in Table 11. This presents token counts of voiced and voiceless targets (/B/ and /P/) and their realization (voiced [B] or voiceless [P]) over a succession of four three-month periods (1;7–

2;5), where the last column gives the results collapsed across periods. In the notation we use, B refers to voiced (labial, coronal, or velar) stops, and P to voiceless stops. Error percentages are indicated in cells for unfaithful realizations. For example, for the period 1;7–1;9, the corpus contains 415 targets with initial voiced stops, 372 of which were realized faithfully, and 43 of which (10.4%) were devoiced.

	Age	1;7–1;9		1;10–1;12		2;0–2;2		2;3–2;5		1;7–2;2	
	Realiz.	[B]	[P]	[B]	[P]	[B]	[P]	[B]	[P]	[B]	[P]
target /B/		372	43	273	17	690	31	775	9	2210	100
target /P/		24	537	16	627	9	551	1	379	50	2094
chi-square		$\chi^2 = 13.8$ $p \leq 0.001$		$\chi^2 = 6.7$ $p \leq 0.01$		$\chi^2 = 7.6$ $p \leq 0.01$		$\chi^2 = 2.4$ (n.s.)		$\chi^2 = 13.6$ $p \leq 0.001$	

Table 11: *Distribution of initial errors in Seth's productions*

Over the monitored period (1;7–2;5), both error types decreased continuously. To determine whether devoicing errors were more frequent than voicing errors, a series of chi-square tests was conducted. Results were significant for all periods except the period of 2;3–2;5.

Figure 8 shows the direction of initial errors in tokens (devoicing versus voicing) as it develops between the ages of 1;7 and 2;5.

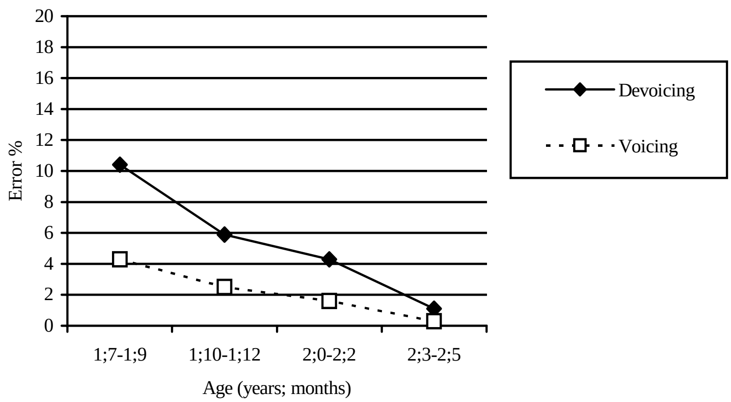


Figure 8: *Direction of initial errors in Seth's productions*

Note that devoicing errors occur about twice as frequently as voicing errors throughout Seth's development.

The dominance of devoicing errors extends to types, as Table 12 shows:[13]

	[B…]	[P…]
target /B…/	68	32
target /P…/	19	108
Chi-square	$\chi^2 = 9.3$ $p \leq 0.01$	

Table 12: *Distribution of voicing and devoicing errors in Seth's productions (types)*

The high proportion of devoicing errors in the early productions of an English learning child apparently clashes with our previous observations for German, where 'voicing' (actually de-aspirating, lenition) errors prevailed. It seems to run against the typological prediction made in section 2, according to which aspiration languages would display errors of the 'voicing' (de-aspiration) type, so that English would parallel German. Upon closer inspection, however, we see that Seth's initial devoicings are not simply neutralizations to the unmarked value.

When we differentiate Seth's initial devoicing errors according to their contexts in the word, it becomes clear that following consonants play a major conditioning role. Figure 9 shows that initial devoicing is much more frequent in targets in which a voiceless obstruent follows (e.g., *bark*, *drink*, *geese*) than in targets which have no following voiceless obstruent (e.g., *boy*, *dog*, *go*):

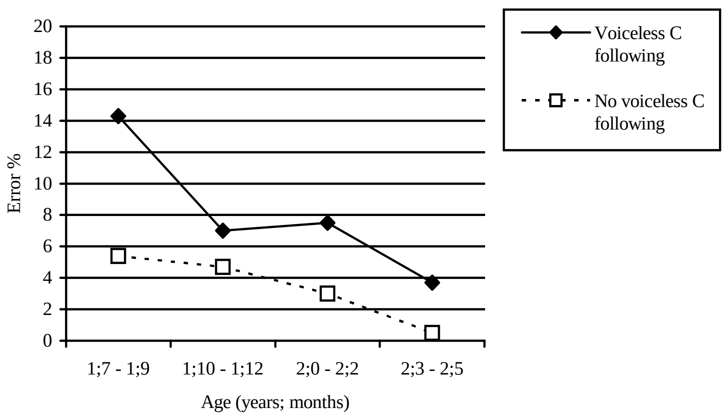


Figure 9: *Initial devoicing in Seth's productions: the role of following consonants*

We used a chi-square test to test the difference in error rates between target categories (words with a following voiced obstruent, a following voiceless obstruent, or no following obstruent), over the entire period (1;7–2;5), and found a strong effect ($\chi^2 = 45.4$, $p \leq 0.001$).

Next, to establish whether voiced obstruents differed from sonorants in their effects on initial devoicing, we broke down the category 'no voiceless consonant following'. Table 13 shows devoicing in three target types: (a) /B…P/ targets,

which have a following voiceless obstruent (e.g. *back*, *diaper*, *grass*), (b) /B…B/ targets, which have a voiced obstruent (e.g. *baby, dog, give*), and (c) /B…R/ targets, which have a following sonorant or vowel ('R') (e.g. *ball*, *door*, *gone*). For each period, Seth's productions are broken down into faithful [B…] and unfaithful [P…] realizations of the target, and error rates are indicated in 'unfaithful' cells.

	Age	1;7–1;9		1;10–1;12		2;0–2;2		2;3–2;5		1;7–2;2	
	Realiz.	[B]	[P]	[B]	[P]	[B]	[P]	[B]	[P]	[B]	[P]
/B…P/		198	33	132	10	197	16	156	6	683	65
/B…B/		77	6	65	5	256	7	370	1	768	19
/B…R/		97	4	76	2	237	8	249	2	659	16

Table 13: *Initial devoicing as a function of following consonants*

Throughout Seth's development, initial devoicing rate is highest for /B…P/ targets. Over the four periods, this error type reaches a much higher average (of 8.7%) than targets /B…B/ and /B…R/ (both 2.4%). Note that in all three categories, a gradual overall reduction of devoicing errors occurs.

The difference between /B…P/ targets and the other targets /B…B/ and /B…R/ turned out to be statistically significant, as Table 14 shows. This compares initial devoicing rates for three targets (/B…P/, /B…B/, /B…R/) for all four periods. Chi-square tests were conducted for the token distribution in Table 12, establishing that /B…P/ targets undergo devoicing significantly more often than targets /B…B/ and /B…R/, while any differences in devoicing rate between /B…B/ and /B…R/ targets are non-significant.

	1;7–1;9	1;10–1;12	2;0–2;2	2;3–2;5	1;7–2;2
/B…P/ versus /B…B/	$\chi^2 = 2.8$ (n.s.)	$\chi^2 = 0.001$ (n.s.)	$\chi^2 = 6.0$ ($p \leq 0.025$)	$\chi^2 = 10.3$ ($p \leq 0.01$)	$\chi^2 = 29.2$ ($p \leq 0.001$)
/B…P/ versus /B…R/	$\chi^2 = 7.6$ ($p \leq 0.01$)	$\chi^2 = 2.0$ (n.s.)	$\chi^2 = 4.1$ ($p \leq 0.05$)	$\chi^2 = 4.4$ ($p \leq 0.05$)	$\chi^2 = 26.4$ ($p \leq 0.001$)
/B…B/ versus /B…R/	$\chi^2 = 0.9$ (n.s.)	$\chi^2 = 1.7$ (n.s.)	$\chi^2 = 0.2$ (n.s.)	$\chi^2 = 0.9$ (n.s.)	$\chi^2 = 0.003$ (n.s.)

Table 14: *Initial devoicing as a function of following consonants*

In sum, devoicing in /B…P/ targets is significantly more frequent than for other targets across periods. It is more frequent than devoicing for /B…B/ targets in two out of four periods, and more frequent than devoicing for /B…R/ targets in three out of four periods. Also, /B…B/ and /B…R/ targets cannot be distinguished in terms of the initial devoicing rate.

We interpret these results as follows. In targets that begin with a voiced obstruent, a following 'P' (voiceless) segment triggers initial devoicing, as compared to a following 'B' (voiced) or 'R' (sonorant) segment, which behave as inactive with respect to initial devoicing. Initial devoicing in /B…P/ targets results in outputs with identical laryngeal features between the word onset (which undergoes it) and a following [spread glottis] obstruent (which triggers it). This is arguably a case of laryngeal harmony of the type that was predicted in section 5 (Table 9). Consequently, this finding supports predictions of the Multiple Feature Hypothesis: English, a language using [spread glottis] to represent its laryngeal contrast, should display activity of this feature in laryngeal harmony, if such harmony were to be found.

Note also that segment types predicted to be phonologically inactive by the Multiple Feature Hypothesis, 'B' (voiced obstruents) or 'R' (sonorants), are indeed inactive. Devoicing rates for target words with following 'B' or 'R' segments fall well below the rate observed for /B…P/ targets. Their shared behaviour is predicted by lack of specification for [spread glottis] under the Multiple Feature Hypothesis. Note that no other featural theory under consideration predicts a shared behaviour, since voiced obstruents will be marked [voice], while sonorants will not bear a distinctive laryngeal representation.

How to account for the fact that initial devoicing marginally occurs in the other targets /B…B/ and /B…R/? We attribute the initial devoicing rate for these targets, which amounts to 2.4% on average in the period 1;7–2;5, to the instability of early lexical representations. That is, the early lexicon contains incomplete featural information for lexical items, manifesting itself in variable productions, with both voiced and voiceless realizations. We suggest that during early production, lexically incomplete featural information is supplemented by three sources. First, context-free markedness effects (that is, omission of [spread glottis]) amount to context-free neutralization, which we observed as voicing in /P…/ targets. Second, copying of the active feature [spread glottis] amounts to laryngeal harmony in /B…P/ targets. Thirdly, a certain amount of random selection occurs. Initial devoicing in targets /B…B/ and /B…R/ occurs when random selection fills in incomplete features in early lexical representations. The fact that initial devoicing is facilitated by, but not categorically restricted to, /B…P/ targets, can thus be explained by an interplay of harmony effects and random specification.

To verify the amount of initial 'devoicing' (actually, aspiration) in Seth's productions, we now turn to the results of phonetic analysis.

6.2.2 *Phonetic analysis.* In order to determine whether devoicing results in a full merger with target voiceless stops, we carried out narrow phonetic transcriptions and conducted acoustic measurements of VOT. First, all stop-initial items (between ages 1;7 and 1;9) were extracted from the digitized sound material. Next, 79 items were removed due to bad quality. For the remaining 605 items, narrow phonetic transcriptions were made by five transcribers (the current authors), and an acoustic analysis (VOT measurements) was conducted. Figure 10 shows mean VOT values (in msecs) for Seth's voiced and voiceless stops (ages 1;7–1;8). Seth's values closely approximate the adult VOT values.

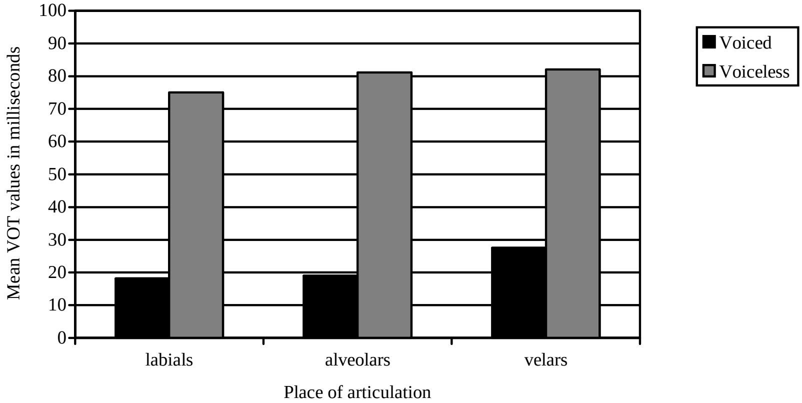


Figure 10: *Mean VOT values in milliseconds for labials, alveolars and velars*

The following criteria were applied for determining an item's error status. A 'devoicing error' was defined as an item whose target has a voiced onset and which was realized with VOT > 30 ms (for labials and alveolars), or with VOT > 50 ms (for velars), and which was also categorized as 'voiceless' by a native listener (one of the current authors). A 'voicing error' was defined as an item whose target has a voiceless onset and which was realized with VOT < 30 ms (for labials and alveolars), or with VOT < 50 ms (for velars), and which was also categorized as 'voiced' by the native listener.

Analysis showed that Seth's devoicing errors resulted in initial stops (e.g. *geese*, *bark*) with mean VOT values which approximate mean VOT values for target voiceless stops (e.g. *tape*). See Figure 11 below. On the basis of these findings, we feel safe in assuming that devoicing errors are 'categorical', in the sense that devoiced target consonants are acoustically indistinguishable from faithfully realized voiceless consonants.

6.2.3 *Initial voicing.* We now turn to target words whose initial consonants are voiceless, and look into patterns of initial voicing, in order to find out whether voiced obstruents behave as phonologically inactive, as predicted by the Multiple Feature Hypothesis.

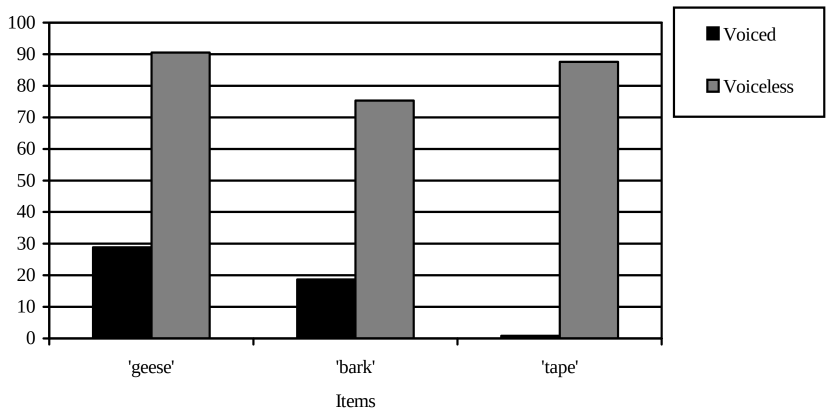


Figure 11: *Errors are categorical*

First, we are interested in the question whether Seth's productions show any effects of anticipatory voicing harmony, analogously to initial devoicing.

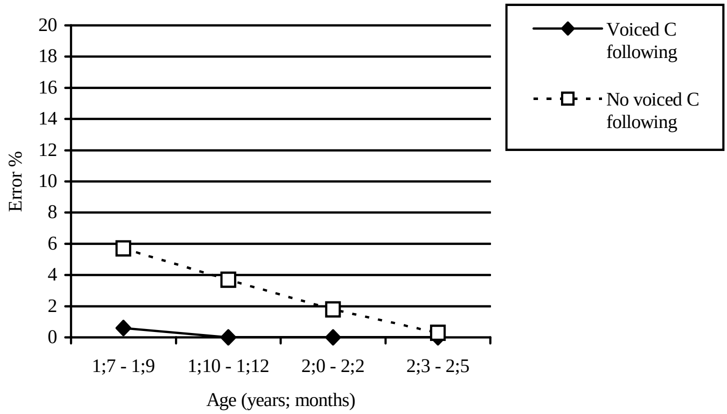


Figure 12: *Initial voicing: the role of following voiced consonants*

Surprisingly, hardly any voicing harmony occurs. The initial voicing rate for /P…B/ targets falls significantly below that of other targets /P…P/ and /P…R/ ($\chi^2 = 11.7$, $p \leq 0.001$). That is, the prediction from the Multiple Feature Hypothesis that voiced obstruents are phonologically inactive is confirmed. We momentarily put aside the question of what causes the harmony-avoiding pattern in /P…B/ targets, and break down the data for /P…P/ and /P…R/ targets, respectively.

Data are broken down for following consonants 'P', 'B' and 'R' in Table 15, which is the counterpart of Table 13 (for initial devoicing).

	Age	1;7–1;9		1;10–1;12		2;0–2;2		2;3–2;5		1;7–2;2	
	Real.:	[B]	[P]	[B]	[P]	[B]	[P]	[B]	[P]	[B]	[P]
/P…P/		23	278	7	295	3	304	1	242	34	1119
/P…B/		1	155	0	214	0	66	0	29	1	464
/P…R/		0	104	9	118	6	181	0	108	15	511

Table 15: *Initial voicing in relation to following consonants (tokens)*

/P…P/ and /P…B/ targets display a gradual decrease of initial voicing errors during Seth's development. As noted above, the case of /P…B/ is most interesting since it shows no voicing errors except one in the first period. As compared to /P…B/, target /P…R/ shows more errors.

Differences between categories turn out to be actually much smaller than in the case of initial devoicing, when measured by chi-square tests. Table 16 compares initial voicing rates of targets /P…P/, /P…B/, and /P…R/.

	1;7–1;9	1;10–1;12	2;0–2;2	2;3–2;5	1;7–2;2
/P…P/ versus /P…B/	$\chi^2 = 10.1$ ($p \leq 0.01$)	$\chi^2 = 5.0$ ($p \leq 0.025$)	$\chi^2 = 0.7$ (n.s.)	$\chi^2 = 0.1$ (n.s.)	$\chi^2 = 11.7$ ($p \leq 0.001$)
/P…P/ versus /P…R/	$\chi^2 = 8.4$ ($p \leq 0.01$)	$\chi^2 = 5.7$ ($p \leq 0.025$)	$\chi^2 = 3.2$ (n.s.)	$\chi^2 = 0.4$ (n.s.)	$\chi^2 = 0.01$ (n.s.)
/P…B/ versus /P…R/	$\chi^2 = 0.7$ (n.s.)	$\chi^2 = 15.6$ ($p \leq 0.001$)	$\chi^2 = 2.2$ (n.s.)	(n.s.)	$\chi^2 = 10.8$ ($p \leq 0.001$)

Table 16: *Initial voicing in relation to following consonants (tokens)*

Phonological inactivity of final /B/ (voiced obstruents) becomes clear from Tables 15 and 16. Since the rate of initial voicing for /P…B/ targets falls far below that of other targets /P…P/ and /P…R/, we may safely conclude that final voiced obstruents fail to condition anticipatory voicing harmony. Non-occurrence of voicing harmony is straightforwardly predicted by the Multiple Feature Hypothesis on the assumption that English is a [spread glottis] language (see again Table 9).

Table 16 also shows significant differences during the first two periods between on the one hand, /P…P/ and /P…B/, and on the other hand, /P…P/ and /P…R/. Since in terms of its featural specification [spread glottis], /P/ forms no natural class with /B/, nor with /R/, both of which are unspecified, these findings are compatible with the Multiple Feature Hypothesis. Note, however, that the relative ease of initial voicing in /P…P/ targets is not predicted by this hypothesis, which has nothing to say about non-harmonic effects. If initial voicing amounts to context-free neutralization, the question is why final /P/ apparently facilitates it. Below we will offer an answer based on the maintenance of lexical contrast. But first we turn to another surprising result shown in Table 16.

The surprising finding is that /P…B/ and /P…R/, which ought to be indistinguishable by the non-specification of /B/ and /R/, nevertheless significantly differ

in period 1;10-1;12, where /P…B/ hardly shows any initial voicing, while /P…R/ does. Upon closer inspection, we find that the inhibitory effect in /P…B/ targets is caused by a single word, *please*, having 170 occurrences in this period, all of which fail to undergo initial voicing. Since *please* is a highly frequent item in Seth's corpus, the inactivity of its initial consonant may be attributed to its relatively stable lexical representation. The high rate of initial voicing in /P…R/ targets in the middle periods (1;10–2;2) is mostly due to alveolar stops: five cases of *turn*, all realized in rapid succession in a single recording session, and two cases of *tan*. Interestingly, the voiced realizations of these items were always preceded by nasals (for example, [sʌn dən] 'sun tan', and [n da$^{\text{ʔ}}$ af] 'N turn off', where the nasal is apparently a realization of 'want'), suggesting a post-nasal voicing process in Seth's phonology. Since alveolar stops regularly alternate with flaps in American English, these may also have been early attempts at flapping. In sum, we suggest that initial voicing in /P…R/ targets is due to phonological factors applying across word boundaries, rather than phonological activity of sonorants following within the target.

In sum, there is no evidence for voicing harmony triggered by /P…B/, confirming the predictions of the Multiple Feature Hypothesis. Target /P…R/ shows no initial voicing except for a temporary unexplained increase during a single period. For /P…P/, some development is visible, with high levels of initial voicing during earlier periods, followed by a sharp decline. It thus seems that segment types /P/, /B/ and /R/ cannot be distinguished as to their effect on initial voicing. This finding is predicted by the central hypothesis that 'voicing' errors amount to a context-free neutralization, a delinking of [spread glottis] → [ ], not conditioned by segments elsewhere in the word.

Finally, we turn to the unexplained low proportion of initial voicing errors in /P…B/ targets. As in German, we attribute initial voicing to context-free omission of [spread glottis], reflecting the instability of early lexical representations. Neutralization occurs at an average level of 2.9% in /P…P/ targets, whereas it is strongly inhibited in /P…B/ (average 0.2%). Our speculative account again starts from the hypothesis that initial voicing amounts to delinking of [spread glottis]). We observe that the key difference between the targets /P…P/ and /P…B/ is that the former contains two [spread glottis] elements, and the latter only one. We suggest that blocking of initial delinking in /P…B/ targets reflects an avoidance of wholesale deletion of [spread glottis].

(11) Initial delinking resulting in complete loss of specified [spread glottis]

P…B → B…B

[spread glottis]

The avoidance of initial delinking in /P…B/ and /P…R/ may thus be construed as a way of maintaining the laryngeal contrast by preserving the single occurrence of [spread glottis].

(12) Initial delinking resulting in partial loss of specified [spread glottis]

P…P → B…P

[spread glottis] [spread glottis]

In contrast, /P…P/ targets have two occurrences, so that initial delinking still preserves one.

In sum, the observed asymmetry between onset devoicing and onset voicing in Seth's early word productions gives evidence from acquisition for the activity of [spread glottis] in English. Phonologically active coda obstruents are lexically specified for this feature, while voiced obstruents and sonorants are unspecified, hence phonologically inactive. The Multiple Feature Hypothesis predicts the observed asymmetry, while other models under consideration fail to account for it.

However, two important questions remain. First, the issue of directionality of harmony effects arises: is laryngeal harmony from coda to onset matched by harmony in the reverse direction, triggered by the onset, and effected in the coda? Second, a major issue arises as to whether the laryngeal harmony as witnessed in /B…P/ targets is due to lexical specification, or rather to surface realization. That is, we assumed that the influence of [spread glottis] is located at the level of lexical representation, but have not presented any evidence bearing on this. We will discuss both issues below.[14]

To answer these questions, we need to look at word onsets and codas separately. For this reason, we will now turn to a selection of Seth's productions, his monosyllables.

6.2.4 *Directionality of harmony: Seth's monosyllables.* Although the Multiple Feature Hypothesis makes no predictions[15] about the directionality of laryngeal harmony, we are nevertheless interested in directionality effects in Seth's data, for two reasons. First, directional asymmetries in laryngeal harmony might provide clues about early lexical representations, related to the relative strength of specification for onset and coda consonants. Second, directionality in laryngeal harmony would strengthen the similarity with other types of consonantal harmony in language acquisition and in speech production. A well-known asymmetry in directionality is found in consonant harmony in children's productions (Menn 1971, Smith 1973, Pater & Werle 2001, 2003, Fikkert & Levelt 2002) as well as in adult speech errors (Fromkin 1973, Shattuck-Hufnagel 1979, Stemberger 1991a,b) including anticipations of voicelessness. We will first address the issue of whether laryngeal harmony is unidirectional in Seth's productions, affecting onsets only, or bidirectional, affecting codas as well.

Before comparing contextual effects in onset and coda devoicing, we briefly address the relative stability of the laryngeal contrasts in onsets and codas in Seth's monosyllables. Figure 13 shows laryngeal error rates for final and initial stops, respectively, during four stages.

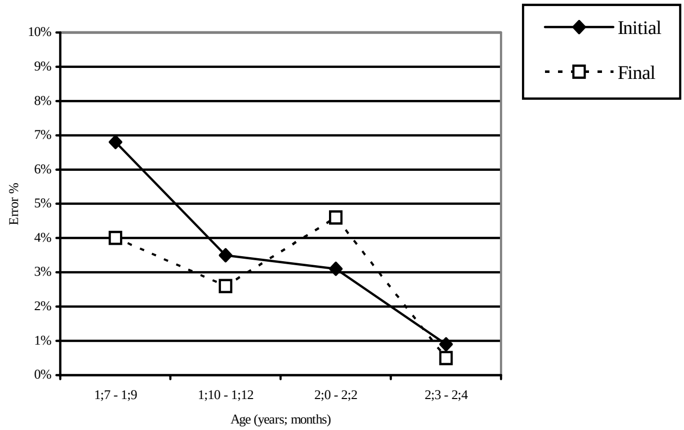


Figure 13: *Laryngeal error rates for initial and final obstruents*

During the earliest stage (1;7–1;9), when Seth's anticipatory devoicing pattern was at its peak, error rates for initial obstruents are slightly (although not significantly) above those for final ones. This suggests that the laryngeal contrast in final position is relatively stable as compared to initial position in early stages of phonological development. Speculatively, this would tie in with our earlier finding about Amahl's development (§6.2, Figure 7), who acquired a stable laryngeal contrast in coda slightly before it stabilized in onset.

The relative stability of the coda contrast naturally leads to the expectation that onset devoicing may be facilitated by voiceless codas, but not vice versa. This expectation stems from the assumption (see §6.2.1) that laryngeal harmony is related to the instability of early lexical representations in the sense that harmony amounts to the influence of a relatively stable lexical specification (typically, a coda) onto a less stable one (typically, an onset). To test the predicted lack of harmony in coda devoicing, we compared onset and coda devoicing in Seth's monosyllables, assessing the degree to which each is contextually conditioned by a voiceless obstruent. From the earlier mentioned database we extracted all targets (151 types, 3064 tokens) starting with a stop, which was voiced in about half of the cases (51.0% of types and 52.8% of tokens). We also extracted all targets (146 types, 2406 tokens) ending in a stop, which was voiced in about one third of the cases (32.9% of types, 28.9% of tokens).

To assess the relative strength of contextual factors in onset and coda devoicing, we first counted voiced and voiceless realizations of /B…/ monosyllables into three categories, whose target ended in a voiceless obstruent, voiced obstruent, or sonorant (including vowels). We will refer to these categories as /B…P/, /B…B/

and /B…R/ respectively. We then counted voiced and voiceless realizations[16] of /…B/ monosyllables, for the three target categories /P…B/, /B…B/, and /R…B/. Characteristic examples of coda devoicing in Seth's database are [bet] 'bed' (1;9) in the category /B…B/, and [fajɲt] 'find' (2;2) in the category /P…B/. The results are shown in Tables 17 and 18.

	[B…]	[P…]
/B…P/	544	42
/B…B/	402	9
/B…R/	553	11
chi-square	$\chi^2 = 25.15$, $p \leq 0.001$	

Table 17: *Initial devoicing in Seth's monosyllables, relative to context*

	[B…]	[P…]
/B…P/	90	5
/B…B/	312	25
/B…R/	65	1
chi-square	$\chi^2 = 3.48$, (n.s.)	

Table 18: *Final devoicing in Seth's monosyllables, relative to context*

Again, a strong effect is found for the contextual conditioning of initial devoicing ($\chi^2 = 25.15$, $p \leq 0.001$). This effect is due to the high proportion of initial devoicing in /B…P/ targets, as compared to other targets. Moreover, as compared to initial devoicing, final devoicing is not contextually conditioned. In spite of some minor differences between targets, there is no effect of onset type ($\chi^2= 3.48$, n.s.), supporting our hypothesis that final devoicing is context-free.

These results point to an interesting asymmetry in the directionality of laryngeal harmony. While onset devoicing anticipates the coda's voicelessness, coda devoicing shows no perseveration of onset voicelessness. That is, laryngeal harmony shares its directionality with other consonantal harmony processes found in acquisition and adult speech errors (see references at the beginning of this section).

Again we argue that the positional interactions in Seth's productions give evidence for an abstract representation of the laryngeal contrast, which is unified between the onset and the coda. As we saw earlier, the phonetic realization for laryngeal contrast in English strongly differs between onsets and codas. In onsets, VOT is the primary cue, while in codas, duration of the preceding vowel, closure duration, and (for some dialects) glottalization, are main cues. Since anticipation of the coda's voicelessness by the onset cannot be reduced to anticipation of the articulatory gestures involved, we have a case that the positional interaction occurs at a more abstract level: that of contrastive specification. This gives evidence from acquisition for representations of laryngeal contrasts involving monovalent

features. More precisely, activity of 'voiceless' obstruents (with non-activity of 'voiced' obstruents and sonorants) supports the specification of the feature [spread glottis], rather than [±voice].

6.2.5 *The level of harmony: lexical versus surface specification.* The final issue is whether initial devoicing in /B…P/ targets is due to lexical specification, or an effect of surface realization. We already saw some evidence from Seth's early productions that laryngeal harmony is governed by lexical specification (see §§6.2.1 and 6.2.4). First, the phonological activity of voiceless obstruents, to the exclusion of voiced obstruents and sonorants, demonstrated in section 6.2, points to a relatively abstract level of representation, which is underspecified for laryngeal features. Second, we discovered two further properties of harmony, its directionality (anticipatory nature) and its non-local nature (passing across an intervening vowel), which both point to lexical representation as the relevant level. Both properties are reminiscent of processes which are assumed to be sensitive to lexical representation, such as speech errors involving place of articulation and voice (see Stemberger 1991a,b).

To further test our hypothesis that lexical specification, not surface realization, is the relevant level conditioning harmony, we checked whether /B…B/ target monosyllables whose final obstruent was produced voiceless due to final devoicing had an increased chance of undergoing onset devoicing as compared to /B…B/ targets whose final consonant remained voiced. As expected, we found no such effect. Thus, for predicting the likelihood for initial devoicing in a /B…B/ item, surface specification of the final obstruent was about equally as informative as its lexical representation. Tentatively, lexical specification alone (not surface realization) may account for laryngeal harmony.

Interestingly, we also found that likelihood of onset devoicing increased as a function of unfaithfulness in the coda, regardless of whether this involved deletion, devoicing, or other segmental changes. This 'unfaithfulness effect' was found for /B…B/ targets ($\chi^2 = 13.61$, $p \leq 0.001$), as well as /B…P/ targets ($\chi^2 = 6.11$, $p \leq 0.025$). It need not have a phonological interpretation; instead we suggest a role for general factors affecting accuracy of realization of the word or utterance as a whole.[17]

The tentative conclusion that lexical representations are involved in initial devoicing is supported by evidence from Seth's monosyllables that shows that onset devoicing is, to some extent, sensitive to lexical frequency of individual items.[18] To test for a correlation between item frequency and onset devoicing, we placed all forty /B…P/ and /B…B/ targets in a rank-order by frequency in Seth's corpus, split the list into two halves (of most frequent and least frequent items), and calculated the error rates for each list. We found that initial devoicing occurs less often in the most frequent items: only 5.1% of the most frequent items underwent initial devoicing, versus 10.7% of the least frequent items. The frequency effect ($\chi^2 = 4.01$, $p \leq 0.05$) is, of course, compatible with developing lexical representations.

7. *Conclusions*

This study of the acquisition of laryngeal contrast in three Germanic languages with binary laryngeal contrasts (Dutch, German, and English) offers evidence supporting the language-specific selection of laryngeal features [voice] and [spread glottis]. The Multiple Feature Hypothesis correctly predicts differences between Dutch and German in children's error patterns in initial obstruents, as the result of neutralization to the unmarked value depends on the language-specific laryngeal feature: loss of [voice] for Dutch, and loss of [spread glottis] for German. However, we observed that the Articulatory Effort Hypothesis could also explain the asymmetry between Dutch and German, assuming that prevoicing and aspiration both pose articulatory challenges to the young child, which are avoided by devoicing (in Dutch) and de-aspiration (in German), respectively. For Dutch and German, we argued that the error patterns in acquisition cannot be fully explained on the basis of input frequency.

Focusing on evidence from the acquisition of English, we argued that an account based on the phonological feature [spread glottis] explains the observed asymmetry between voiceless obstruents and other consonants. In Seth's early productions, we found anticipatory devoicing, a case of laryngeal harmony, triggered by following voiceless obstruents but not by following voiced obstruents, nor by sonorants. This finding was interpreted as to support the Multiple Feature Hypothesis, i.e. languages with binary laryngeal contrasts differ in their 'active' laryngeal features, either [voice] or [spread glottis]. For English, a language which selects [spread glottis] as its active laryngeal feature, this correctly predicts that only voiceless obstruents trigger harmony.

Finally, we argued that articulatory effort alone cannot account for observed effects of anticipatory devoicing because of its non-local nature and the abstractness of the specification involved. Anticipatory devoicing arguably involves an abstract level of featural organization, that of contrastive specification. We presented additional evidence to support the hypothesis that the level of representation that is relevant for laryngeal harmony is lexical representation: its non-locality, its sensitivity to lexical frequency, and its insensitivity to the presence of the triggering segment in the output.

Perhaps the main interest of harmony patterns in children's productions resides in the possibility of testing the nature of lexical representations in early childhood. Even within a single language, laryngeal contrasts may be realized by rather different articulatory gestures (which correspond to different acoustic parameters) in syllable onset and coda. Evidence from children's early productions for laryngeal harmony between coda and onset, two positions which differ in the articulatory implementations of the laryngeal specification, suggests that young children (starting round the age 1;6) already construct phonological representations that abstract away from the phonetic detail which differentiates specific positions.

Acknowledgements

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Notes

1. An alternative to Iverson & Salmons' multiple laryngeal features is that of Avery & Idsardi (2001) who express the features in more phonetic terms in three dimensions: Glottal Width (for aspiration languages like English), Glottal Tension (for voicing languages, such as Dutch) and Larynx Height for languages which have ejectives or implosives in their segment inventories. In this paper, we use the terminology [voice] and [spread glottis] to express the phonological contrasts.

2. Here we focus on word-initial stops.

3. VOT interacts with place of articulation features (Lisker & Abramson 1964): dorsal stops have a longer VOT than both coronal and labial stops; in turn, coronal stops have a longer VOT than labial stops.

4. Other monovalent features may also be used to capture laryngeal contrasts cross-linguistically, such as [constricted glottis] or [stiff vocal cords]. Languages may have more than one feature; for example, Thai, which has a three-way laryngeal contrast, employs both features [voice] and [spread glottis].

5. One could also look at the frequency of voiceless vs. voiceless stops collapsed across different prosodic positions, i.e. collapsed across word-initial, word-medial and word-final position (see Zamuner 2007). Based on these types of calculations, one finds that voiceless stops are overall more frequent than voiced stops. Input frequencies would then match the patterns of production seen in Dutch acquisition data.

6. Data in the Nijmegen database were collected and transcribed by Susan Powers, Jürgen Weissenborn, Wolfgang Klein, Heike Behrens, and Max Miller.

7. The stronger trend toward voicing in tokens can be attributed to the fact that many prefixed words start with /bə/ or /ɡə/. A related issue, which we leave for future work, is how prosodic factors (mainly, stress) affect the salience of laryngeal contrasts in the input. For example, contrasts in onsets of stressed syllables may be more salient than those in unstressed syllables, such as prefixes.

8. As far as we know, no gestural accounts have been proposed which assign a single laryngeal gesture to onset and coda, thus spanning an entire syllable. Such accounts would necessarily be more abstract than the standard accounts, moving closer to a phonological representation.

9. Dutch and German have word-final neutralization, hence monosyllables cannot be used to test predictions on laryngeal harmony. Logically, laryngeal harmony might affect initial and medial consonants in polysyllables in these languages, but unfortunately, relevant cases in the Dutch and German databases were too rare to base any conclusions on.

10. Analysis is necessarily based on types, since Smith (1973) does not present token counts.

11. Amahl's mother spoke English as her fourth language, after Hindi, Bengali and Marathi. According to Smith (1973:7-8), her speech was characterized by 'fuller voicing of voiced obstruents'.

12. Stop-initial function words rarely occurred during the early stages of Seth's development. Moreover, targets for function words were difficult to establish.

13. If a single type occurred as both voiced and voiceless, it was coded as unfaithful. For example, bark was coded as [P...] because it occurred with both voiced and voiceless initial stops.

14. A third question, which we will briefly address at the end of this section, concerns item-specificity: to what extent is the devoicing effect restricted to particular target words?

15. Of course, we predict that if right-to-left (perseverative) laryngeal harmony were to be found, then it should be of the devoicing type, rather than of the voicing type, since English employs [spread glottis] as its active feature. However, coda voicing effects were generally too rare in Seth's productions for this prediction to be testable.

16. Other realizations, such as those involving onset deletion, were left out of consideration.

17. Some /B…P/ items were found in which initial devoicing occurred even though the final obstruent was left deleted, for example, [pli] 'blink' and [kij] 'geese' [1;7]. Although such cases may seem to constitute strong evidence for the relevance of lexical representation, their relevance is somewhat undermined by the observation that deletion in /B…B/ items also increased chances of devoicing in onset. Both cases can be explained by the general unfaithfulness factor discussed above.

18. Thanks to Joe Stemberger for suggesting this to us.

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Exceptions to Final Devoicing

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Some dialects of Dutch show systematic exceptions to final devoicing in the first person singular of verbs ending in a long or tense vowel and a fricative. This observation raises questions about the morphology – what makes the first person singular of verbs so special? –, and about the phonology – what makes fricatives after long vowels so special? As to the morphological side of things, this paper argues that the first person singular suffix, which used to be a schwa, is still present as an abstract vocalic position. From the phonological point of view, I argue that Dutch fricatives have a phonological length contrast rather than a voicing contrast. Since (empty) syllabic positions and consonant length both are expressed in the phonotactic dimension, it is expected that they interact.

1. *Introduction: data and the issue*

All West-Germanic languages display the effects of the process of final devoicing (FD).[1] This process is illustrated in (1) for standard Dutch: an underlyingly voiced obstruent devoices when it occurs at the end of a syllable. The obstruent is underlyingly voiced because it appears as voiced in forms where it does not end the syllable, for instance because a following morpheme starts with a vowel. In (1) the contrast is illustrated by the verb stem *bet* 'to wet', which has an underlying /t/, and the noun *bed* 'bed' which has an underlying /d/. The [d] appears when the vowel-initial plural suffix is added.

(1)	*bet*	/bɛt/	[bɛt]	'(I) wet'	– /bɛt+ən/	[bɛtən]	*betten*	'(we) wet'
	bed	/bɛd/	[bɛt]	'bed'	– /bɛd+ən/	[bɛdən]	*bedden*	'beds'

As far as we know, there are no Dutch dialects that do not have FD at all. On the other hand, there are quite a few dialects that display exceptions to FD in certain well-defined morphological contexts (De Schutter & Taeldeman 1986, De Vriendt & Goyvaerts 1989, Goeman 1999, van Bree 2003).

A relatively widespread phenomenon found both in eastern and southern dialects of Dutch (including Flemish) is that the final fricative of a verbal stem with a long vowel in the final syllable remains voiced in the first person singular. The following facts are from fieldwork carried out in 2003 (Schoemans & van Oostendorp 2004):[2]

(2)

Town	final -v		final -ɣ	
Beuningen	ɪk χəløːw^{v}	'I believe'		
Noord-Deurningen			ɪk saːɣ	'I saw'
Rossum	ɪk bliːv	'I stay	ɪk maːɣ	'I may'

Schoemans & van Oostendorp (2004) did not find any comparable data with voiced coronal fricatives, and there were more instances of labial fricatives than of velars.[3] In some cases, the segment alternating with voiceless [f] was transcribed phonetically as [w] rather than [v] (while transcriptions like [w^{v}] may indicate partial devoicing) – a fact that we will briefly discuss in section 3 below.

The data in (2) present the type of exceptional behaviour that will be studied in this article. At least two questions arise. In the first place, why are fricatives (after long vowels) involved, rather than stops? Secondly, why is the first person singular involved rather than some other morphological form? Both issues will turn out to be closely related, although we will concentrate here mostly on the former one.

Based on data from Dutch dialects in the so-called GTR database[4], and dialectological work by van Bree (2003), Goeman (1999), Weijnen (1991) and Schoemans & van Oostendorp (2004), the main argument will be that a sufficiently sophisticated view of representations obviates the need for a complex analysis using constraints promoting paradigm uniformity.

This paper is organised as follows: I will first lay out a morphological approach to exceptions of this type and argue that an approach in terms of paradigm uniformity – devoicing would differentiate the first person singular too much from other forms – faces severe problems; an (Items-and-Arrangement) approach which assumes that all underlying morphemes are expressed in the phonological output representation, on the other hand, seems more successful. In section 3 I discuss the analysis of voicing in fricatives, and show how the phonological behaviour of these elements can be made to follow from their representation: if we assume that fricatives prefer to co-occur with the distinctive feature [spread glottis], and if [spread glottis] segments are preferably long (both of which claims have been made in the literature), the relevant facts are direct consequences. In section 4, I will frame the debate in terms of Optimality Theory for the sake of concreteness, even though the issue, and most of the arguments pro and contra, are quite independent from this particular choice. Section 5 presents a short conclusion.

2. *Two approaches to the interaction between morphology and phonology*

There are two main approaches to capturing the special effect of the first person singular:

1. Paradigmatic. The first person singular should resemble 'related' forms as much as possible; application of final devoicing would increase the differ-

ences between forms in the paradigm to an unacceptable level (cf. van Bree 2003).

2. Structural. The first person singular has some property which blocks final devoicing (cf. Zonneveld 1978).

These two approaches correspond roughly to two different views on morphology (the Word-and-Paradigm vs. the Item-and-Arrangement model; Hockett 1958, Robins 1959): the paradigmatic approach seems to be consistent with a view of morphology as a function that relates words, as essentially unstructured units, to each other, while the structural approach fits best with a view of morphology in which it is assumed that words are structured units of morphemes.

Much modern literature within Optimality Theory (OT) converges on paradigmatic approaches to facts such as the ones that are currently under analysis (see, for instance, Benua 1997, Burzio 1998 and McCarthy 2002b). However, this choice does not necessarily follow; Items-and-Arrangement views of morphology could also be formalized within OT.

In order to compare these two approaches to phonology-morphology interaction, we need some analytical tools to deal with final devoicing. Several of these are familiar from the current literature (see also other articles in this volume); here we will use the following (Lombardi 1991; cf. also Steriade 1997):

(3) FINALDEVOICING (FD)
Voiced obstruents are only allowed in a position preceding a tautosyllabic sonorant.

This constraint describes the effect we need directly. It has to be ordered above the relevant faithfulness constraint, here IDENT-IO(voice), which disallows changing the feature value for voicing, in order to be active in the grammar. The faithfulness constraint is given in (4) and the ranking in (5):

(4) IDENT-IO(voice)
Underlying specifications for voicing should be respected.

(5) FD » IDENT-IO(VOICE)

The tableau in (6) shows how the correct output is derived:

(6)

input: /bɛd/	FD	IDENT-IO(voice)
☞ [bɛt]		*
[bɛd]	*!	
[pɛd]	*!	
[pɛt]		**!

In the paradigmatic approach, we need a special faithfulness constraint in which the output is not compared to the input, but to a different output form (most likely, another form in the paradigm). Such a constraint could take various shapes – see Benua (1997), Kager (1999), McCarthy (2002b) for illustrative proposals – but we will formulate it as follows:

(7) IDENT-OO(VOICE)
The specification for [voice] of the form under evaluation should be the same as the specification for [voice] in some designated other form in the paradigm.

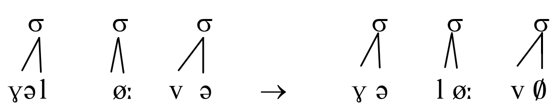
I will assume for the sake of the argument that the “designated other form” in the case of *ik geleuv* ‘I believe’ is the infinitive *geleuven*:

(8)

input: /ɣəlø:v/ [ɣəløv:ən]	IDENT-OO(VOICE)	FD	IDENT-IO(VOICE)
☞ [ɣəlø:v]		*	
[ɣəlø:f]	*!		*

What would the alternative, structural analysis look like? This approach would assume that, even though the vowel of the 1SG suffix has disappeared, it has not done so without leaving a trace. For instance, it might assume that the suffix consists of a phonetically empty vowel position (symbolised as ∅ below), protecting the consonant from being devoiced (because in this approach, too, devoicing would only affect consonants in absolute coda position). Diachronically, this would involve the following development:

(9)



The resulting configuration would not be subject to final devoicing, at least under some definitions of this constraint since it would not occur in syllable coda. This approach[5] requires some degree of abstractness within the phonological representation, viz. a zero morpheme in the shape of an empty vowel, but it should be noted that it does not require reference to the notion of a paradigm, the exact definition of which has also been a subject of debate.

Let us compare the structural approach to the paradigmatic one. There are at least three problems with the latter. The first of these concerns the geographical positioning of the phenomenon involved. From dialect-geographic study, it appears that exceptions to FD of the type discussed above are always found in the vicinity of areas where the 1SG suffix is still overt. Tilligte, for example, borders on an area where *ik geleuve* still occurs; the form has even been reported as an indigenous variant for Tilligte itself (Goeman 1999). The same is true for southern

dialects displaying the process, such as Ghent (cf. Goossens 1977): they are always in the vicinity of dialects in which the schwa is still pronounced, or the schwa variant can even still be found, variably, in the dialect in question. This can be clearly seen in Figure 1, which displays a map of the (European) Dutch-speaking language area (The Netherlands and Flanders), where the circles denote dialects with 'exceptions' to final devoicing for any of the verbs 'to live', 'to stay' and/or 'to give' (past tense): boxes indicate dialects in which the 1SG form of any of these verbs ends in a schwa:[6]

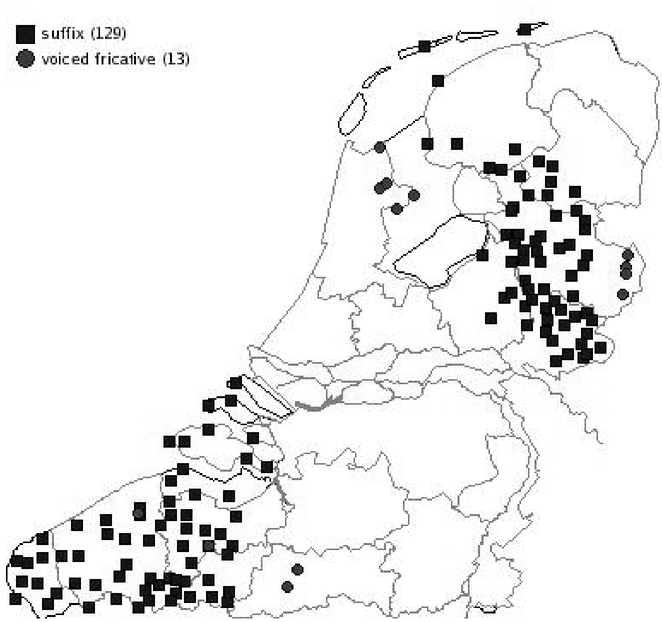


Figure 1: *Schwa-deletion and voiced fricatives*

Especially the fact that the pattern is found in two unconnected areas is very suggestive. If we assume that geography mirrors language change in this case, this is a very strange and unexpected state of affairs. We have to posit three stages of development:

1. *ik geleuve*. During this stage IDENT-OO(VOICE) is not active, because schwa protects the fricative from becoming devoiced. Since it is usually assumed that faithfulness constraints are lowly ranked by the language learner, unless there is evidence to the contrary, the constraint will have a low position in the hierarchy during this stage.
2. *ik geleuv*. In this stage, some constraint is responsible for schwa deletion (e.g. FINAL-C, McCarthy 2003, Swets 2004 and references there); at exactly the same time, IDENT-OO(VOICE) should become highly ranked, even though it is not clear if there is a formal connection between the two constraint movements.

3. *ik geleuf*. At this point, IDENT-OO(VOICE) should again be lowly ranked since it no longer affects the phonology of any segment.

The output-to-output faithfulness constraint has to move up and down during language change; it is unclear what is the relation between this fact and the disappearance of schwa. In particular, we could expect IDENT-OO sometimes to move up in dialects without recent schwa apocope, so that we would find individual spots where exceptions to FD are not surrounded by places where there is still a schwa. As pointed out above, this does not seem to happen.

Notice that the structural approach does not suffer from this problem. The language change is incorporated, as it were, into the phonological representations. The order of events in this case would be that the schwa would first be deleted, leaving behind its structural position. After a while this unstable situation would be resolved by loss of the empty position, and the fricative would end up in a coda. Within this approach, there is no reason why a coda fricative would ever 'spontaneously' create an empty vowel at the end of the word.

The second problem with the paradigmatic approach concerns the structure of the paradigm. In the presentation of the paradigmatic account above, we assumed that we could establish in some way that the "designated other form" in the paradigm in the case of *ik geleuv* is *geleuven*; the latter form is the infinitive and plural form of the verb (for all persons) in the Standard language. On closer scrutiny, this view is problematic. In some of the dialects under discussion, it is not clear what the role of this form in the paradigm is. The dialects surrounding Tilligte, for instance, have a plural ending in *–t*, so that actually all other forms in the present tense are geleuft with a devoiced cluster.

(10)	1 SG	geleuv	1 PL	geleuft
	2 SG	geleuft	2 PL	geleuft
	3 SG	geleuft	3 PL	geleuft

The infinitive is *geleuven* in these dialects, but it is not clear why it should be the infinitive that should block final devoicing. There also is no apparent reason why the influence of this 'designated other form' should be restricted to the 1SG; the other forms in the paradigm could have become *geleu*[vd], but as far as I have been able to ascertain, this form is never attested. In fact, the 2SG form is *geleuf* in many dialects if it precedes the subject (e.g. in questions where there is subject inversion). Yet the fricative is never voiced in this case.[7]

Because the notion of a paradigm does not play a crucial role in the structural approach, this problem does not affect it. The form *geleuv* is evaluated independently of other forms in the paradigm, and it does not matter what these other forms are, although one could argue that in the absence of any other voiced fricative form, the language learner would no longer have a reason to posit such a form in the first place.

The third problem with a paradigmatic account is that exceptions to final devoicing always involve fricatives. In this approach, it is unclear why fricatives

should be more sensitive to paradigmatic influence than other consonants. We could reformulate the relevant faithfulness constraint in the following way:

(11) IDENT-OO(Voice, fricatives)
The specification for [voice] in fricatives for the form under evaluation should equal the specification for [voice] in some designated other form in the paradigm.

A constraint of this type would not rank very highly on the scale of explanatory adequacy. Since fricatives do not support voicing contrasts as easily as stops do, one might actually expect the opposite state of affairs.[8] However, the structural approach does not immediately offer a valid alternative. There is no reason why a plosive could not occur in the onset of an otherwise empty syllable in the same way as a fricative. This problem needs to be solved first before we can use the status of fricatives as a fatal objection to the paradigmatic approach, and this is therefore the topic of the next section.

3. *Voicing and fricatives in Dutch*

At first sight, it may seem absurd that fricatives are involved in exceptions to FD, regardless of our morphological theory: phonetically they are less compatible with voicing than plosives (cf. again fn. 7 above). It is even the case that in those cases in which exceptions to final devoicing are not triggered by the morphology, we seem to find the inverse pattern: fricatives devoice before plosives do. In a survey of Dutch dialects, van Bree (2003) mentions that

> “not all potential target sounds take their turn at the same time: devoicing clearly takes place earlier with fricatives than with occlusives (…); this might be related to the fact that the unmarked state for fricatives is voicelessness.”[9]

One could object to this that the fricatives in these dialects tend to have a sonorant type of realization; e.g. the voiced [v] was sometimes transcribed as [w] in our data. One might hypothesize that this means that the sound is really a sonorant /w/ underlyingly; but such an assumption does not explain why the segment devoices in other contexts, for instance when it occurs next to a voiceless obstruent. Other sonorants never devoice at the end of the word, so that we conclude that at least phonologically /v/ still counts as an obstruent. On the other hand, the realization [w] for an underlying fricative [v] is not unexpected; such a pronunciation will enhance the perceptibility of the voicing of this segment.[10]

We will have to take into account the fact that there is a difference between those cases in which morphology is involved, and in which fricatives tend to get voiced, and those cases in which it is not, and in which fricatives are not voiced at all. For now, let us concentrate on the former case. Interestingly, there is another well-known example of a language in which fricatives constitute exceptions to FD, viz. Turkish (Kaisse 1986, Rice 1993):[11]

(12) stops may alternate:

yüzük	‘ring, NOM.SG’	~	yüzügü	‘ring, ACC.SG’
kağıt	‘sheet, NOM.SG’	~	kağıdı	‘sheet, ACC.SG’
şarap	‘wine, NOM.SG’	~	şarabı	‘wine, ACC.SG’

fricatives do not alternate:

az	‘little’
ev	‘home’

There is arguably a special relation between fricatives and voice if we look at it from a cross-linguistic perspective. According to Maddieson (1984: 48), “bilabial, dental and palatal non-sibilant fricatives are found to occur without a voiceless counterpart more often than with one”.

Van Oostendorp (2002) argues on the basis of phonotactic distribution that in some West-Germanic dialects – and in particular in Dutch – the opposition voiced vs. voiceless for fricatives should be replaced by the opposition short vs. long.[12] Phonetically, these oppositions are clearly related (Slis & van Heugten 1989; van Rooy & Wissing 2001). This explains facts such as those above: in Turkish, fricatives are not sensitive to FD since their representation does not include the feature [voice] (an idea which is clearly also present in the approach of Rice 1993 referred to above). The fact that short (i.e. voiced) fricatives should occur more frequently than long (i.e. voiceless) ones is also hardly surprising from this point of view.

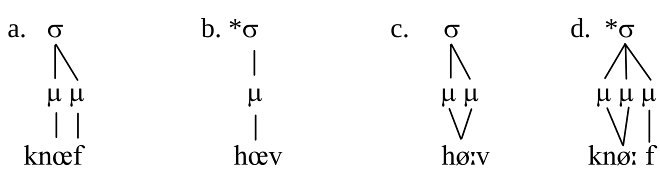
At first sight, it might seem problematic to replace the voicing opposition with a length opposition completely in Dutch – at least in Standard Dutch and the dialects under consideration here –, but there is evidence that shows that the two dimensions are correlated, e.g. the fact that short lax vowels (almost) exclusively occur before voiceless fricatives and long (tense) fricatives (almost) exclusively before voiced ones.

(13)

knuffel	[knœf]	‘hug’	*[knœːf]
heuvel	[høːv]	‘hill’	*[hœv]

This pattern can be most easily accounted for if we assume that long vowels occupy two moras, short vowels only one and if voiceless (i.e. long) fricatives are represented as moraic. Stressed syllables must then consist of maximally (and minimally) two moras:[13]

(14)



In (14a), a short vowel is followed by a 'long' consonant, which is fine. In (14b), the short vowel is followed by a short consonant; this structure is too short – it contains less than the minimum of two moras. In (14c), a long vowel is followed by a short consonant, which is again fine. In (14d), a long vowel is followed by a long consonant, which results in an illicit three-mora structure.

There is some empirical support for this assumption in the work of Ernestus (2000: 177). Based on a corpus of spontaneous (Standard Dutch) speech, Ernestus notes that

> "Clusters of fricatives of the same place of articulation arise when a word-final fricative is followed by a word-initial one. These clusters are generally realized with a duration that is shorter than the duration of two segments (...). In what follows, clusters consisting of two segments with the same manner and place of articulation will be referred to as geminates.
>
> (...) The problem is that fricative geminates are always realized as voiceless, independently of their context, exact duration, etc."

A somewhat more complicated argument for the same relation between frication and length, finally, comes from a number of Brabantish and Flemish dialects of Dutch (De Schutter & Taeldeman 1986) in which the deletion of /t/ in clusters causes the fricative in such clusters to become devoiced. So, *hij doe*[t v]*eel* 'he does a lot', is realised as *hij doe*[f]*eel*. The same does not happen (or happens much less frequently) if the consonant which followed the /t/ in underlying form is a plosive. This could be analysed as a case of opaque interaction between progressive assimilation – which is indeed a rule that applies in Dutch in clusters ending in fricatives – and t-deletion. On the assumption that voiceless fricatives are long, however, a different solution is also possible: deleting /t/ would leave a position to be filled up by the fricative, which would thereby become long. Devoicing would thus be a form of compensatory lengthening.

Based on these arguments, we postulate the following correlation:

(15) If a fricative is attached to one position, it is voiced, and vice versa.

This might lead one to conclude that the phonological distinction between voiced and voiceless fricatives is one of length rather than of voicing. However, in the usual case fricatives devoice in Dutch just like stops. Devoicing is usually described as delinking of the feature [voice] or of the Laryngeal node (Lombardi 1991, 1995, 1999). If we were to subscribe to a length theory of fricatives, we would need an alternative account – which would need to say that somehow fricatives lengthen at the end of the syllable or at the end of the word. It is not immediately clear that such an account can provide an explanation for the fact why the fricatives in first person singulars do not lengthen.

The second problem seems even more severe. One of the most well-known aspects of Dutch phonology is that it has voicing assimilation in obstruent clusters. This assimilation process involves stops and fricatives alike. One example will suffice to show the problem:

(16)	a/f/+/d/oen	>	a[vd]oen	'take off'
	a/f/+/t/akelen	>	a[ft]akelen	'go to seed'

In autosegmental terms, this change can easily be described in terms of a feature [voice], spreading from the stop to the fricative. This then is a clear contraindication to the assumption that the distinction among fricatives is primarily one of length.

Since there seem to be quite a few problems with the length-based account, we will now turn to an alternative account based on traditional features. Vaux (1998) argues in favour of the view that voiceless fricatives are represented as [+spread glottis] (like aspirated stops). The proposal is dubbed Vaux's Law in Avery & Idsardi (2001), and we will formulate it in the form of an implicational constraint:

(17) VAUX'SLAW: Fricative ⊃ [spread glottis]
'Fricatives preferably have the feature [spread glottis]'

Vaux (1998) presents arguments from (several dialects of) Armenian, as well as from Sanskrit, Pāli, the historical development of Modern Greek and from Thai for this implication.

Some of the facts of Dutch discussed above might be amenable to an analysis along the same lines. For instance, the fact that fricatives seem more resistant to devoicing than stops can be understood, because voiced fricatives might be regarded as (literally) more marked than voiceless ones, in the same sense that aspirated stops are more marked than unaspirated ones. Devoicing a fricative involves adding [+spread glottis], which is incompatible with an analysis in which final devoicing is an instance of delinking the Laryngeal node.[14] On the other hand, we would obviously need an account of final devoicing that would regard it in some cases as a form of final fortition (such an account seems feasible, however; cf. Iverson and Salmons 2003a,b, 2006, forthcoming; Vaux & Samuels 2005; Kiparsky 2006).

Also relating to the proposed similarity in representation between voiceless fricatives and aspirated plosives, is that it is well-known that aspirated plosives are known to be substantially longer than unaspirated plosives. In this light, consider the proposal by Ringen (1999) of a constraint MULTILINK, which demands that [spread glottis] must be linked to two positions, capturing the length effects mentioned above:

(18) MULTILINK
The feature [+spread glottis] must be linked to two positions.

The relation expressed by MULTILINK could be seen as a (mutual) enhancement of contrast of length and a laryngeal feature. Ringen uses this constraint to explain why underlyingly aspirated stops in Icelandic are not allowed to surface as aspirated when they occur in a cluster. In this case, they occur as 'preaspirated' stops, sharing the feature [spread glottis] with an [h]. The fact that in English on-

set clusters, aspiration spreads from the stop to the onset ([pl̥]ead, [tr̥]ain, etc.) could be explained by invoking this constraint in a similar way.

Extending this interpretation of MULTILINK, we could also use it to explain why voiceless fricatives are (preferably) long or in a cluster. It has indeed been proposed in the literature that a feature [tense] on fricatives is phonetically cued primarily by length (cf. Jessen 1998 for an overview; cf. also van Rooy & Wissing 2001). To the extent that [tense] and [spread glottis] can be regarded as the same formal object, MULTILINK can be regarded as a formalisation of this idea. A short voiceless fricative prefers to share its [spread glottis] specification; it can do this either by being long (assuming the parts of the long fricative help each other to satisfy MULTILINK), or by occurring in a voiceless cluster.

In order to account for the fact that Standard Dutch does not have aspirated (i.e. [spread glottis]) stops, we invoke the following constraint:

(19) *NGO, NOGEMINATEONSETS:
Stops in onsets are never long (no initial geminate stops)

The constraint clearly has some typological value, since geminates are absent from onset positions more often than anywhere else. MULTILINK, together with VAUX'SLAW can help us to formulate the behaviour of intervocalic fricatives in a much more insightful way, as will be shown now. An interesting aspect of our current findings is that it allows us to understand the dual behaviour of voicing in fricatives: it behaves both as a length distinction and as a feature difference, because it involves both.

An important observation is that in one of the regions (the Twente region in the East, on the border with Germany) in which we find exceptions to final devoicing as discussed here, we find aspirated stops in foot-initial onsets. This is important since it could undermine the basis of our account in which the two classes of obstruents are represented differently. If both fricatives and plosives are organized according to a [spread glottis] contrast rather than according to [voice], it is not clear why one would be an exception to final devoicing whereas the other could not.

However, the observations made above about the difference in behaviour between plosives and fricatives in intervocalic position also hold in these dialects (Schoemans & van Oostendorp 2004), so that it seems that in this position there still is a phonological length difference. Further, inspection of the data in the GTR database shows that the aspiration contrast is restricted to word- or foot-initial position; in other positions we find a voicing contrast instead. Since we are analyzing the exceptions to final devoicing as special cases of 'intervocalic' fricatives, aspiration in these dialects pose no specific problem to the account proposed here.

4. *OT Formalisation*

In the preceding sections we have seen, first, that a structural account of the special behaviour of the first person singular seems more promising than a paradigmatic account, and, second, that a theory of voicing in fricatives which is based

on length is feasible although not unproblematic. We will now try to put the pieces together to see whether we can produce a coherent analysis that can deal with all of these facts at the same time. I have chosen OT as my framework of analysis, since it offers a fairly standard lingua franca in which the discussion can be framed.

The core of the analysis are the constraints VAUX’SLAW, requiring fricatives to be [spread glottis] (‘voiceless’), and MULTILINK, requiring [spread glottis] to be spread across two positions. It is necessary, first, to show how these two constraints can account for the behaviour of fricatives in intervocalic position, in interaction with a constraint on syllable well-formedness, to the effect that long consonants are not allowed after long vowels (recall the facts in (13-14) above; the constraint is referred to as *μμμ here) and assuming that faithfulness constraints are ranked conveniently (i.e. vowels are not allowed to change their length, but fricatives can change both their length and their voicing specification):[15,16]

(20) a./aːsaː/, /aːsaː/	*μμμ	MULTILINK	VAUX’S LAW
☞ i. aːzaː			*
ii. aːsaː		*!	
iii. aːsːaː	*!		
b. /azːaː/, /asːaː/			
☞ i. asːaː			
ii. asaː		*!	
iii. azaː			*!

The input in (20a) has a long vowel preceding the fricative. The winning candidate in (20ai) has a voiced fricative, but no alternatives are available with a voiceless fricative; (20aii) is a short voiceless fricative violating MULTILINK, and a long voiceless fricative can only be introduced here at the cost of introducing a superheavy syllable in the middle of a word.

Alternatively, the inputs in (20b) have a short vowel. The winning candidate can now satisfy all relevant constraints, since it can contain a long and voiceless fricative. Alternatives will always either have a short voiceless fricative (20bii) or a voiced fricative (20biii), violating markedness.

In order to describe the behaviour of fricatives at the end of the word, we need to take a closer look at the actual structure of the word in that position. Dutch syllables are usually minimally and maximally bimoraic; trimoraic syllables are only found at the end of words. As a matter of fact, the end of word is even less restrictive. Here, we even find extra (coronal) consonants beyond the template. We thus have words such as herfst ‘autumn’ where herf is a trimoraic syllable and st is a cluster of ‘extrasyllabic’ segments, which are outside the syllabic structure proper. I assume that these extra positions are also available for the second half of geminates at the end of words:

(21) /aːs/,/aːz/	*µµµ	MULTILINK	VAUX'S LAW
☞ aːsː			
aːs		*!	
aːz			*!
aːzː		*!	*

/as/, /az/	*µµµ	MULTILINK	VAUX'S LAW
☞ asː			
as		*!	
az			*!
azː		*!	

On the other hand, in the exceptional cases such as *ik geleuv* in (1) can be dealt with if we assume that (a) here the fricative appears in an onset of an empty-headed syllable (as was argued above), and (b) geminates are not allowed in an onset in this position:

(22) /ɣəløːv/	*µµµ	*NGO	MULTILINK	VAUX'S LAW
☞ ɣə.løː.vV				*
ɣə.løːf.fV	*!			
ɣə.løː.ffV		*!		
ɣəløː.fV			*!	

(22) gives a comparison of [ɣəløːv] with all of the conceivable possible outputs that have a voiceless consonants. The winning candidate violates VAUX'S LAW (since it does not have the feature [spread glottis]), but it beats all its competitors on some higher-ranking constraint.

The difference between the dialects that do allow for this type of structure and those which do not can now be reduced to the question whether or not the dialect allows an empty vowel in this particular configuration. The empty vowel should be licensed by the 1st person singular morpheme. We can assume that the constraint responsible for this is the following (cf. Kurisu 2001 and references cited there for related, although not completely identical proposals):

(23) REALIZEMORPHEME
A morpheme should somehow be expressed in the phonological surface representation.

In the dialects which allow these exceptions, REALIZEMORPHEME is ranked above whatever constraints there are against empty vowels (*EMPTY). For dialects which do not allow for this possibility, there are two options. The least interesting option is that in these dialects the ranking is *EMPTY » REALIZEMORPHEME. Somewhat more interesting would be the proposal that the ranking does not change, but the first person singular suffix loses its status as an independent mor-

pheme, so that REALIZEMORPHEME no longer plays a role and therefore does not license the empty vowel, which will no longer be postulated in the phonology.

Notice, however, that we still lack a formal answer to the question of why stops do not display the same kind of behaviour as fricatives. The answer is that in this case the relevant property (voice) is not dependent on syllable positions directly, and not interpreted in terms of length.

Yet according to this definition, [voice] also cannot appear in the onset of otherwise empty syllables, since it is not followed there by a tautosyllabic sonorant. Consider the following tableau:

(24) /baːd/ 'bathe'	*μμμ	FD
i. baːdV		*!
☞ ii. baː.tV		
iii. baːt	*!	
iv. baːd		*!

This tableau proves that obstruents will always be devoiced, regardless of the morphological structure. The forms in (24i) and (24iv) have a voiced obstruent which is not followed by a sonorant; the form in (24iii) has a superheavy syllable. (24ii) avoids the problem of a superheavy syllable by introducing an empty vowel, and the FD problem by making the obstruent preceding the empty vowel voiceless.

5. *Conclusion*

In this article, I have shown that a sophisticated view of representations can provide us with insight in a phenomenon that seems simple at first sight, but which turns out to be quite problematic on closer inspection. The fact that exceptions to final devoicing are only found in first person singular forms of verbs ending in a (long vowel plus) fricative may seem almost trivial at first sight, but I hope to have shown that at present it seems to shed light on at least two different debates in linguistic theory: morphology-phonology interaction, and phonological representations.

On the one hand, this phenomenon can be most satisfyingly accounted for in a theory which does not rely so much on paradigm uniformity as on one which postulates a somewhat abstract morpheme for the 1SG. Notice that this analysis can also be seen as an argument in favour of (some amount of) phonological structure; it does not work without being able to refer to the syllabic position 'onset'.

Similarly, the reason why fricatives behave differently from stops required explanation, and preferably one which links this particular difference between fricatives and stops to other differences, such as that in assimilation in clusters. Again, this could be attained by studying the representations we need more closely. This paper therefore will hopefully provide a further impetus to the revived interest in representational issues in phonology.

Notes

1. There are many differences between these languages; for instance, it is well-known that some varieties of Yiddish do not (or do no longer) devoice obstruents at the end of the word (Lombardi 1991, 1995; Wetzels & Mascaró 2001) and it is claimed for Frisian that FD did not start to operate until the beginning of the 20th century (Tiersma 1985). See van Bree (2003) for an overview.

2. Schoemans & van Oostendorp (2004) present a larger set of data.

3. I will not discuss the different behaviour of distinct places of articulation; notice that our findings correspond in part to a hierarchy according to which velars in general are more prone to devoicing than coronals, which in turn devoice more easily than labials.

4. This database is available online at http://www.meertens.knaw.nl/projecten/mand/data.html.

5. Zonneveld (1978) is the Urheber of this idea in the Dutch literature, albeit for facts which are quite different from the ones studied here; see van Oostendorp (2005) for a comparison; cf. also Kaye, Lowenstamm & Vergnaud (1990) and many others, for theoretical proposals regarding the nature of such empty positions.

6. Note that in the north-east, on the border of the IJsselmeer (IJssel lake), there are a few circles which are not close to dialects were schwa is pronounced. It is possible that schwa deletion has started to operate relatively recently in this region. Another possible reason is that these are so-called West-Frisian dialects, and very similar to Frisian in many ways. As was noted in footnote 1, final devoicing did not apply to Frisian for a very long time (the province of Fryslân borders on the West-Frisian area, but data from this language have not been included in the survey on which this map was based), which explains the white spot on the province of Fryslân (the province in the north, below the three rightmost islands). Potentially, then, these dialects are indeed on the border of a linguistic area – albeit one at the opposite side of the lake.

7. A complicating factor is that the subject is always a second person singular pronoun or clitic; in some dialects this is an (underlyingly voiced) fricative, and fricative clusters are never voiced in Dutch (cf. Zonneveld, this volume). Another problematic case is where the pronoun (and especially the clitic) starts with a vowel; in that case lack of devoicing can be understood as resyllabification. In many dialects, however, the second person pronouns and clitics start with a glide; in this case there should be no problem in voicing the fricative.

8. A reviewer points out that “many varieties of Netherlandic – not just dialects, but also colloquial varieties – are losing voicing distinctions in fricatives. In the midst of such a change, it becomes somewhat less surprising that the pattern treated here would arise – fricative devoicing is part of a broader pattern.” It is indeed true that many varieties of Dutch seem to be losing the voicing distinction in fricatives; notice that this means that laryngeal faithfulness is apparently less important for fricatives than for stops.

9. “niet alle in aanmerking komende klanken [komen] tegelijk aan de beurt […]: bij de fricatieven vindt er duidelijk eerder verscherping plaats dan bij de occlusieven […]; dat kan er verband mee houden dat de ongemarkeerde toestand waarin een fricatief zich bevindt, die van stemloosheid is” (van Bree 2003: 7; my translation MvO).

10. It is well-known that languages of the world may have (especially labiodental) segments that are difficult to classify as either fricatives or approximants. See e.g. Padgett (2002) for Russian and Hamann & Sennema (2005) for German, as well as references cited there for, for instance, other Slavic languages and Hungarian.

11. Rice (1993) and Avery (1996) give these as an example of ‘sonorant obstruents’: the voicing of fricatives is a result of a feature (non-laryngeal) Sonorant Voice, but the stops are voiced by laryngeal [voice] and the final devoicing rule targets only the latter. This does not explain, however, why the asymmetry is exactly in this way (it seems to be similar in many of Rice’ (1993) examples; to be more precise, there is no example where stops have Sonorant Voice, but fricatives have [voice]).

12. See Avery (1996) and Iverson & Salmons (2003a,b, 2006, forthcoming) for related positions. Kraehenmann (2003) offers an extensive treatment of the fortis/lenis distinction in Alemannic in terms of length.

13. See van Oostendorp (2002) for a full analysis.

14. A reviewer points out that it would be possible to regard devoicing as delinking of [voice] and subsequent addition of [spread glottis] as a type of enhancement. Such an analysis would be most straightforward if not the whole Laryngeal node is delinked.

15. In the following tables, there is sometimes more than one input representation in the lefthand table: these will surface in the same way due to the irrelevance of most faithfulness constraints.

16. If we assume that neither vowels nor fricatives can change in any way, the resulting language will be one in which voicing (or length) of fricatives is not dependent on syllabification; but if either voicing or length of fricatives can change, or if the vowels can change, we will obtain a pattern resembling the pattern established here (albeit in some cases one where all contrasts are neutralized).

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Prevoicing in Dutch Initial Plosives
Production, Perception, and Word Recognition

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Prevoicing is the presence of vocal fold vibration during the closure of initial voiced plosives (negative VOT). The presence or absence of prevoicing is generally used to describe the voicing distinction in Dutch initial plosives. However, a phonetic study showed that prevoicing is frequently absent in Dutch. This article discusses the role of prevoicing in the production and perception of Dutch plosives. Furthermore, two cross-modal priming experiments are presented that examined the effect of prevoicing variation on word recognition. Both experiments showed no difference between primes with 12, 6 or 0 periods of prevoicing, even though a third experiment indicated that listeners could discriminate these words. These results are discussed in light of another priming experiment that did show an effect of the absence of prevoicing, but only when primes had a voiceless word competitor. Phonetic detail appears to influence lexical access only when it helps to distinguish between lexical candidates.

1. *Introduction*

This article focuses on the phonological voicing distinction in Dutch initial plosives, that is, the distinction between [+voice] and [–voice] in those plosives. Although most languages contrast these two phonemic classes (which I will refer to as voiced and voiceless plosives), the way in which this phonological distinction is implemented phonetically varies across languages. Lisker & Abramson (1964) investigated eleven languages and measured the time between the release of a plosive and the onset of vocal fold vibration, which they referred to as Voice Onset Time (VOT). They established that, across languages, VOT is essentially tri-modal. The three categories based on VOT were: plosives with a negative VOT, produced with a voiced lead (i.e., with voicing during the closure); plosives with a slightly positive VOT, produced with almost no aspiration; and plosives with a clear positive VOT, produced with aspiration (see also Keating 1984).

Some languages, such as Thai, employ all three modes in a three-way voicing distinction. Most languages, however, have a two-way voicing distinction, which is implemented by two adjacent modes, one of which is associated with the voiced, and the other with the voiceless plosive. Keating, Linker & Huffman (1983) surveyed 51 languages and observed that almost all these languages use at least some kind of voiceless unaspirated plosive and that of the two categories

contrasting the voiceless unaspirated plosive, fully voiced and voiceless aspirated plosives are about equally common.

Germanic languages such as Danish, English and German contrast voiceless unaspirated and voiceless aspirated plosives in initial position (Keating 1984). Dutch, however, is unusual among Germanic languages in that it does not include this contrast. Instead, Dutch, along with other languages such as Arabic, Bulgarian, French, Japanese, Polish, Russian and Spanish, has a traditional voicing contrast (Keating 1984, Lisker & Abramson 1964). That is, the voiced plosives are produced with a voice lead, which I will refer to as prevoicing, and the voiceless plosives are produced with little or no aspiration. Figure 1 shows an example of a voiced plosive with prevoicing and an example of a voiceless plosive. There are three plosives in Dutch which belong to the voiceless category, namely [p], [t], and [k], while there are only two plosives which belong to the voiced category, namely [b] and [d]. The velar voiced plosive [g] only occurs in loanwords and is therefore not discussed here.

In this article I will first describe the production of prevoicing and discuss the outcomes of a study by van Alphen & Smits (2004), which investigated the occurrence of prevoicing in Dutch initial voiced plosives and the role of prevoicing in perception. The outcomes show an interesting paradox between production and perception: prevoicing appears to be frequently absent in Dutch initial voiced plosives, but the presence of prevoicing is nevertheless a very strong cue for the perception of voicing in these plosives. In order to fully understand the influence that prevoicing has on perception it is important not only to study phoneme perception, but also to study word recognition. Words are after all the meaningful units which a listener has to recognize in order to retrieve the message of the speaker. Two priming experiments and a discrimination experiment will be presented which investigate the effects of two types of prevoicing variation on word recognition. The results of these experiments will be discussed together with the outcomes of a priming study by van Alphen & McQueen (2006) in which the influence of lexical word competitors starting with a voiceless plosive was examined. These experiments lead to the conclusion that word recognition is sensitive to prevoicing variation, but only to the type of variation that is relevant for the distinction between lexical candidates.

2. *Production of prevoicing*

Prevoicing refers to the presence of vocal fold vibration during the closure of the plosive. According to the myoelastic-aerodynamic theory of phonation (van den Berg 1958), the vocal folds will vibrate only when they are properly adducted and tensed, and when there exists a sufficient transglottal pressure gradient to result in a positive airflow through the glottis from the lungs. When a vowel or continuant consonant is produced it is not very difficult to obtain sufficient transglottal pressure: the vocal tract is open and therefore the supraglottal pressure will be lower than the subglottal pressure as long as there is sufficient air in the lungs.

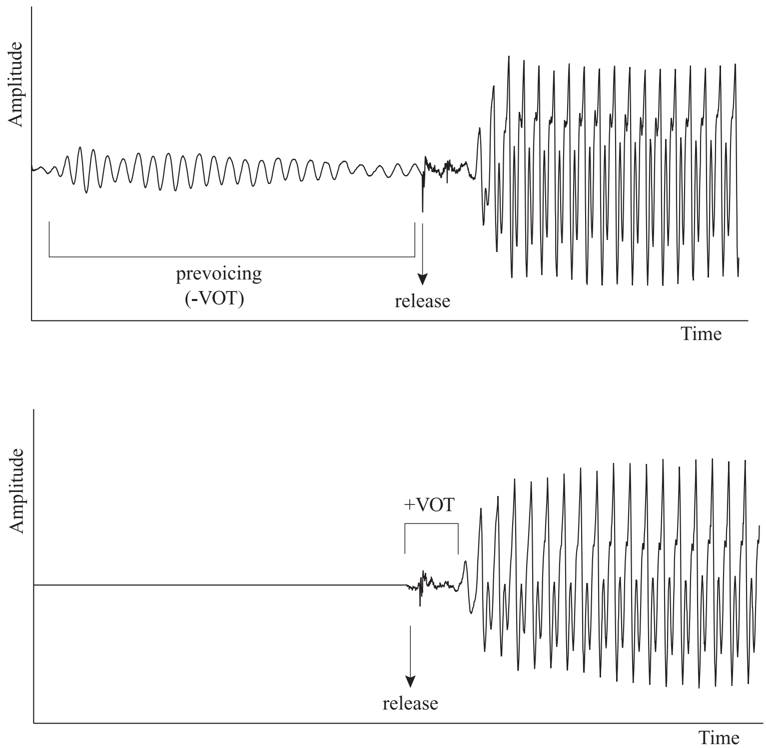

Figure 1: *Waveforms of the initial voiced plosive and part of the vowel of the Dutch word /bo:t/ (upper panel) and of the initial voiceless plosive and part of the vowel of the Dutch word /po:t/ (lower panel).*

During the production of a plosive, however, all out-going airways are closed. The blocking of out-flowing air, causes the supraglottal pressure to increase rapidly, which results in a rapid decrease of the transglottal pressure. It is therefore relatively difficult to let the vocal folds vibrate during the closure. As the volume above the glottis increases, the build up of supraglottal pressure is delayed to some extent, and therefore a sufficient transglottal pressure for voicing may be obtained for some period of time. Enlargement of the supraglottal cavity will thus help to initiate and maintain voicing. This enlargement can be obtained actively, by lowering the larynx, raising the soft palate, advancing the tongue root, or drawing the tongue dorsum and blade down (see Westbury 1982), or passively when the walls of the supraglottal cavity are lax which allows them to expand in response to the internal pressure (Rothenberg 1968).

Children acquire the production of prevoicing relatively late (Kewley-Port & Preston 1974; see also the article by Kager et al., this volume). This also suggests that prevoicing production is relatively difficult. Nevertheless, studies on the production of prevoicing in languages such as Polish (Keating, Mikos & Ganong 1981), Lebanese Arabic (Yeni-Komshian, Caramazza & Preston 1977) and Euro-

pean French (Caramazza & Yeni-Komshian 1974) show that adult speakers rarely omit prevoicing when producing voiced plosives. Only one study, on Canadian French (Caramazza & Yeni-Komshian 1974) has found a substantial degree of overlap between the VOT distributions of voiced and voiceless plosives; no less than 58% of the voiced tokens in that sample (N=90) were produced without prevoicing. Caramazza and Yeni-Komshian argued that in Canadian French the VOT values are shifting as a result of the influence of Canadian English.

Until recently, however, Dutch has not been systematically investigated in terms of occurrence of prevoicing in the production of voiced plosives. It is important to know how prevoicing varies naturally in order to understand effects of prevoicing variation on speech perception. The way in which the speech recognition system treats a particular acoustic property largely depends on the variation in the occurrence of this property in natural speech. In one of my recent studies (van Alphen & Smits 2004) the occurrence of prevoicing in Dutch was therefore investigated.

Van Alphen & Smits (2004) asked ten Dutch speakers to produce 32 real words and 32 nonsense words with initial voiced plosives (/b/ or /d/). These items were presented randomly in a list with fillers (including the same items starting with voiceless plosives), such that the listener's attention was not drawn to the voicing distinction. The results showed that 25% of the tokens with initial voiced plosives were produced without prevoicing. The proportion of prevoiced tokens was found to be influenced by the following factors: sex of the speaker (male or female), place of articulation of the plosive (labial or alveolar), and the phoneme following the plosive (vowel or consonant). All these factors might have an effect on the vocal tract volume or on the extent to which the vocal tract can be expanded. The smaller the volume of the vocal tract, the faster the supraglottal pressure increases and the more difficult it is to produce prevoicing. Male speakers are expected to have a larger vocal tract size than female speakers, which makes it easier for males to produce prevoicing. In line with this expectation, male speakers produced prevoicing more often than female speakers (86% versus 65%). The place of articulation of a plosive was expected to influence the extent to which the vocal tract can be expanded passively due to variable size of the oral cavity behind the point of constriction. For dental stops, the pharyngeal walls and part of the soft palate can yield to expansion of the oral cavity, while for labial stops these surfaces plus all of the tongue surface and parts of the cheek can participate in the expansion (Houde 1968, Rothenberg 1968). The oral cavity can thus be expanded more during the production of labial plosives than during the production of dental plosives. Van Alphen and Smits indeed found that labial plosives were more often produced with prevoicing than alveolars (79% versus 72%). Finally, the following phoneme was expected to affect the vocal tract size and the extent to which the different mechanisms (passively and actively) could expand the vocal tract size, and thus the proportion of prevoiced tokens. No effect of vowel height was found, but plosives followed by a vowel were more often prevoiced than plosives followed by a consonant (86% versus 65%).

Although it seems that prevoicing was absent in the cases where the aerodynamics made it harder to produce prevoicing, it can not be the case that prevoicing is simply too difficult to produce in particular cases, since other studies on prevoicing production in other languages (e.g., Keating, Mikos & Ganong 1981, Yeni-Komshian, Caramazza & Preston 1977, and Caramazza & Yeni-Komshian 1974) did not find such a large proportion of unprevoiced tokens. This suggests that Dutch speakers make less effort to produce prevoicing, resulting in a relatively large proportion of voiced plosives without prevoicing, especially in the cases in which it is difficult to produce prevoicing. We can only speculate about the reason for this. It may be the case that the way in which the voicing distinction in Dutch is implemented phonetically is changing as a result of the influence of English on the Dutch language.

3. *The role of prevoicing in the perception of the voicing distinction*

Now that we know that prevoicing is frequently absent in Dutch initial voiced plosives, we can ask what influence this has on perception. Are the voiced tokens produced without prevoicing still perceived as voiced? In other words, is the production of prevoicing essential for the plosives to be perceived as voiced, or are other acoustic cues present and strong enough to evoke a voiced percept? We know from the previous literature that VOT is not the only acoustic property which covaries with the voicing distinction in plosives (see for example Jessen 1998 for German; Slis & Cohen 1969 for Dutch). Van Alphen & Smits (2004) therefore examined what other acoustic properties were present in the acoustic realizations of Dutch initial plosives which could serve as potential perceptual cues to the voicing distinction. The following six measures were obtained from a sample of 480 voiced tokens and 480 voiceless tokens: duration of prevoicing, duration of the burst, power of the burst, spectral centre of gravity of the burst, F_0 immediately after burst offset, and F_0 movement into the vowel (see van Alphen & Smits for a detailed description of the measurements). Except for the F_0 immediately after burst offset, all measures showed a significant difference between phonologically voiced and voiceless plosives (that is, tokens which were intended to be voiced or voiceless by the speaker). In addition to the finding that voiced plosives had more prevoicing than voiceless plosives (which were never produced with prevoicing) the data showed that all three measures involving the burst (the duration, power and spectral centre of gravity) were lower for voiced than for voiceless plosives. Finally, the mean F_0 difference (that is, the difference between the F_0 in the middle of the following vowel and the F_0 immediately after the burst) was positive for tokens starting with voiced plosives, consistent with a rising F_0, while it was negative for tokens starting with a voiceless plosive, consistent with a falling F_0. These differences indicate that the speech signal contains a variety of potential perceptual cues for the voicing distinction.

Sixteen listeners were then asked to identify the 960 tokens as voiced or voiceless. Regression tree analysis of the responses indicated that, of all measured acoustic properties, the presence or absence of prevoicing was by far the strongest cue to the voicing distinction as perceived by listeners. All tokens produced with

prevoicing were perceived as voiced. Tokens without prevoicing, however, were perceived either as voiced or voiceless. In those cases, the perceived voicing category depended on the value of the other acoustic cues in the signal. When those cues were in favour of the voiced category, the tokens were perceived as voiced, despite the absence of prevoicing. The acoustic cue which most strongly influenced listeners' responses to tokens without prevoicing was different for the two places of articulation. The perception of voicing in labial plosives was influenced most strongly by the F_0 difference from the burst of the plosive into the vowel: a higher F_0 difference (that is, a clearly rising F_0 pattern) yielded a higher proportion of voiced responses. The perception of voicing in alveolar plosives appeared to be influenced most strongly by the spectral centre of gravity of the spectral noise of the burst: a higher spectral centre of gravity yielded a lower proportion of voiced responses. Nevertheless, these secondary cues were rather weak in comparison to prevoicing. Of all tokens produced without prevoicing which were intended to be voiced, 37% were identified as voiceless. The absence of prevoicing clearly decreases the probability that a token is perceived as voiced.

The results of the study by van Alphen & Smits (2004) indicate that the presence or absence of prevoicing plays an important role in the phonetic realization and the perception of the phonological voicing distinction in Dutch initial plosives. The role of prevoicing is, however asymmetric: voiceless plosives are always produced without prevoicing, while voiced plosives are not always produced with prevoicing. In line with this, tokens produced with prevoicing are always perceived as voiced, while tokens produced without prevoicing are not always perceived as voiceless.

So far, I have argued that prevoicing has a strong influence on the identification of Dutch initial plosives as voiced or voiceless. Of course, speech perception involves more than the perception of phonological features or the perception of single phonemes. The core process in speech perception is the recognition of words. Since words are the units which convey meaning, the recognition of words is an essential component of how the listener retrieves the message of the speaker. Thus, the next step one has to take in order to fully understand the effect of prevoicing variation on speech perception is to examine the influence of prevoicing variation on the recognition of words.

4. *Effects of fine-grained acoustic details on word recognition*

Word recognition involves the mapping of the speech signal onto stored lexical knowledge. As the utterance unfolds over time, multiple lexical candidates are activated as a result of the acoustic input. The activation of a lexical candidate at a particular moment in time reflects the goodness of fit with the available acoustic input at that moment. The candidate that eventually matches the acoustic input best will be recognized. It appears that the activated lexical candidates compete with each other for recognition; the most strongly activated candidate will suppress the activation of the other lexical candidates and win the competition (see McQueen 2004 for an overview of the evidence for the existence of competition between lexical candidates).

The speech signal is highly variable, however, and not all acoustic information is relevant for the recognition of words. Therefore, the assumption is that listeners perform a detailed phonetic analysis of the acoustic input prior to lexical access. At the prelexical level, the incoming speech signal is normalized and useful information is extracted from the speech signal and translated into abstract representations. Many different units have been proposed as prelexical representations, including syllables (Mehler 1981), semi-syllables (Massaro 1987), phonemes (Foss & Blank 1980; Nearey 2001), allophones (Luce, Goldinger, Auer & Vitevitch 2000) and features (Stevens 2002). So far, research has not provided us with conclusive evidence singling out one of these units.

These prelexical representations, whatever their exact nature, are assumed to activate word representations. The prelexical level acts thus as an intermediate level at which the speech signal is analyzed and filtered. On this account, it is important to distinguish between acoustic detail that is normalized away at the prelexical level and that which is passed on to the lexical level. It could be the case that at the prelexical level discrete decisions are made (for example in the FUL model by Lahiri & Reetz (1999) in which a phoneme is either [+voice] or [–voice]), and that most acoustic detail is thus normalized away. In contrast, it could also be the case that the prelexical level preserves part of the acoustic detail such that the output of the prelexical level is graded (for example in the recent version of Shortlist by Norris, McQueen & Cutler (2000), which involves graded activation of prelexical representations.) If the latter assumption is correct, one particular token of the labial plosive may result in more activation of the prelexical representation for [b] or for [+voice] than another token does. In other words, the question is how much acoustic detail is still present in the information that reaches the lexical level.

Many studies have shown that lexical activation is in fact sensitive to fine-grained acoustic information (see McQueen, Dahan & Cutler 2003, for a detailed overview). These studies show that the degree of activation of lexical candidates is influenced by fine-grained differences in the speech signal and thus suggest that small acoustic details are preserved by the prelexical level and can reach the lexicon. In other words, they challenge the view that discrete decisions (for example phonemic decisions) are made at the prelexical level. It seems that graded activation of prelexical representations is passed on continuously to the lexical level. This is in line with spoken-word recognition models such as TRACE (McClelland & Elman 1986) and SHORTLIST (Norris 1994, Norris, McQueen & Cutler 2000), in which information flows continuously from a prelexical level of processing to the lexical level.

Among the studies which report effects of fine-grained acoustic details on lexical activation, there are a number of studies which focus on variation in VOT. Andruski, Blumstein & Burton (1994) obtained variations in English VOT by removing one third or two thirds of the original positive VOT of voiceless plosives which appeared word initially. They examined the influence of these VOT variations on the activation of lexical candidates in a within modality associative priming experiment. In this experiment, listeners were asked to perform a lexical deci-

sion task on spoken targets which were preceded by spoken primes. A target word, for example queen, was preceded by either a semantically unrelated prime, such as bell, or by a semantically related prime, such as king. All related primes started with a voiceless plosive and appeared in three different VOT conditions: with unaltered VOT, with two thirds of the original VOT, or with one third of the original VOT. Furthermore, half of the related primes were words which had a voiced word competitor, that is, changing the initial voiceless plosive into the matching voiced plosive resulted in a word, for example *pear* (*bear* is also an existing word). The other half of the primes were words which did not have a lexical competitor, for example *king* (*ging* is not an existing word). The reaction time (RT) patterns of the lexical decisions showed that listeners were faster to make lexical decisions to targets when they were preceded by related primes than when they were preceded by unrelated primes. Lexical decisions to targets preceded by the primes with one third of the original VOT were significantly slower than lexical decisions to the same targets preceded by primes with unaltered VOT. The presence of a voiced word competitor seemed not to influence these effects. Furthermore, these effects of VOT manipulation only appeared when the delay between the offset of the target and onset of the prime was short (50 ms); they did not appear when the delay was longer (250 ms).

Utman, Blumstein & Burton (2000) explored the influence of similar VOT differences on lexical activation using a uni-modal identity priming experiment. This time, both words and non-words starting with voiceless plosives were used as primes. Spoken targets were preceded by the same natural tokens of those targets, or by tokens in which the VOT was shortened. The findings for the word primes were consistent with the findings by Andruski et al. (1994): lexical decisions to spoken word targets, such as *kiss*, were slower when these targets were preceded by spoken primes, such as *kiss*, of which only one third of the original VOT was preserved, than when these targets were preceded by primes which were identical (with unaltered VOT). When targets and primes were non-words, however, no effect of the VOT reduction was found on the lexical decisions.

McMurray, Tanenhaus & Aslin (2002) investigated the effect of VOT variation on lexical access in English. The outcomes of their eye-tracking experiment showed that the mean proportion of fixations to two target pictures of a beach and a peach varied gradually as a function of the VOT of the initial plosives.

These experiments show that differences in English positive VOT are not normalized away at the prelexical level, but that this type of acoustic detail is passed on to the lexical level where it can affect the degree of lexical activation. Can similar effects be observed for differences in the negative VOT of initial plosives in Dutch? This question was addressed in the priming experiments presented below. In order to understand the predictions which were made for Dutch, however, it is important to first consider the differences between VOT in English and Dutch.

Although in both English and Dutch VOT plays an important role in the phonological voicing distinction of word-initial plosives, the phonetic realization of voiced and voiceless plosives is rather different in the two languages. While in

English the informative value of VOT lies in the positive VOT range, that is, in the exact duration of aspiration, in Dutch it is the presence or absence of prevoicing which seems to be important (van Alphen & Smits 2004). In English, the phoneme boundary between voiced and voiceless plosives in terms of VOT is not fixed, but varies on a continuous scale, for example as a function of speaking rate (Green & Miller 1985, Summerfield 1981). English listeners are therefore required to make fine temporal distinctions along the VOT dimension in order to perceive the plosive as voiced or voiceless. In contrast, Dutch listeners do not need to establish the exact duration of the VOT to perceive the voicing distinction, since, as described above, the voicing distinction in Dutch is signalled by the presence or absence of prevoicing, rather than by the exact amount of prevoicing. Similar suggestions have been made by Keating, Mikos & Ganong (1981) about the comparison between the informational value of VOT variation for English versus Polish listeners.

Given these differences between VOT in English and Dutch, the first prediction is that as long as Dutch initial plosives have prevoicing, differences in the exact amount of prevoicing will not affect lexical activation. After all, the exact duration of prevoicing will not help listeners to distinguish between two alternative lexical candidates such as beer (bear) or peer (pear). Therefore, this type of uninformative acoustic detail should be normalized away at the prelexical level. As a result, shortening prevoicing duration should not affect lexical activation. The difference between the presence or absence of prevoicing, however, does carry information about the Dutch voicing distinction. Recall that van Alphen and Smits (2004) showed that the absence of prevoicing decreased the probability that that token was voiced. Therefore, the second prediction is that the deletion of prevoicing would affect lexical access.

5. *Experiment 1*

To test these predictions, three prevoicing values were chosen (0, 6 and 12 periods of prevoicing) such that the smallest duration was zero and such that the physical difference between the subsequent prevoicing durations was the same. Importantly, all three degrees of prevoicing fell within the natural range of prevoicing duration as established by van Alphen and Smits (2004). The expectation was to find an effect of the difference between the absence and presence of prevoicing (0 versus 6 periods of prevoicing), but not of prevoicing shortening (12 versus 6 periods of prevoicing). Furthermore, the experiments explored whether a possible effect of prevoicing differences would be influenced by the frequency of the prime words. High frequency words are usually recognized faster than low frequency words (e.g., Solomon & Postman 1952). Therefore, it may be the case that listeners are less sensitive to fine-grained acoustic variation in high frequency words than in low frequency words.

Following Andruski et al. (1994), the associative priming task was chosen. But primes and targets were presented in different modalities (spoken primes were followed by visual targets), rather than within one modality. The reasons for this were twofold. First, Andruski et al. only observed effects when the delay between

the offset of the prime and onset of the target was short (50 ms). Since the VOT manipulation in Dutch appeared even earlier in the prime word than in English (prevoicing appears at the beginning of the plosive while aspiration appears after the burst of the plosive), it seemed preferable to present the targets immediately after the offset of the spoken prime. If both prime and target were presented auditorily with zero delay, the prime could mask the end of the target. The cross-modal version of the associative priming task avoids this problem. Second, the use of a visual target ensured that what was tested was activation at the lexical level, rather than activation at the prelexical level as a result of possible phonological overlap between prime and target. Although most primes and targets did not overlap phonologically (for example, *bloem* ‘flower’ – *roos* ‘rose’) some of the primes and targets did (for example, *brood* ‘bread’ – *boter* ‘butter’).

The underlying idea in the use of the associative priming task is that the processing of a stimulus (the prime) may facilitate the subsequent processing of a following stimulus (the target) if the prime is semantically related to the prime. To measure the influence of the presentation of the prime on the processing of the target, participants are asked to perform a task such as lexical decision on the targets. The RTs of these decisions are then compared to the RTs in a baseline condition, in which the target is preceded by a semantically unrelated prime (see, for example, Marslen-Wilson & Zwitserlood 1989).

If it is indeed the case that deletion of prevoicing affects lexical activation while differences in the amount of prevoicing do not, the following patterns should be observed: faster lexical decisions should be made to targets such as *roos* (‘rose’) when the preceding semantically related prime *bloem* (‘flower’) starts with prevoicing than when the same prime has no prevoicing; and there should be no difference between lexical decisions to targets preceded by related primes with 12 periods of prevoicing and those to targets preceded by primes with 6 periods of prevoicing. If it is the case, however, that the prelexical level does not normalize away the difference in prevoicing duration (12 versus 6 periods of prevoicing) such that this type of variation does affect lexical activation, different priming effects should be found for primes with 12 and 6 periods of prevoicing. The expectation would then be that primes such as *bloem* starting with 12 periods of prevoicing will result in stronger activation of the lexical representations of those words (e.g., the lexical representation of *bloem*) than the same primes starting with 6 periods with prevoicing, since plosives with 12 periods of prevoicing are further away from the phoneme boundary.

5.1 *Method*

Participants

Forty-eight students were paid to take part in the experiment. None of them reported any hearing loss.

Materials

Two types of words were selected as primes: 40 high frequency words (HF words), and 40 low frequency words (LF words). The mean frequency of the HF

words was 97 per million words and the mean frequency of the LF words was 2 per million words (from the CELEX lexical database, Baayen, Piepenbrock & Gulikers 1995). Half of the HF words started with a /b/ and the other half started with a /d/. Of the LF words, 25 words started with a /b/ and 15 with a /d/. All words were mono- or disyllabic; the disyllabic words all had a strong-weak stress pattern.

For each word a semantically related word was selected to serve as a visual target. This was done by asking 23 subjects to give their associations for each word. An associated word was regarded as a good target when the word was given in response by more than 25% of the subjects and when the difference between that associated word and the next most frequent associated word was greater than 10%. The mean frequency of the targets associated with the HF prime words was 133 per million words and the mean frequency of the targets associated with the LF prime words was 42 per million words. For each target an unrelated prime was also chosen which matched the related prime in length and started with the same phoneme (/b/ or /d/). In addition to the 80 word targets there were 40 non-word targets preceded by (unrelated) primes starting with a voiced plosive (half of them started with a /b/ and half of them with a /d/). Furthermore 200 other targets were paired with primes that started with a phoneme other than a /b/ or /d/: 120 non-word targets with unrelated primes; and 80 word targets, of which 20 were preceded by a related prime and 60 by an unrelated prime. The design is summarized in Table 1.

Stimulus construction

All primes were recorded several times on digital audio tape (at a sampling rate of 48 kHz with 16-bit resolution) by a male native speaker of Dutch. The utterances were then digitized at a sample rate of 16 kHz. For the three prevoicing priming conditions and the unrelated condition, tokens were chosen which were produced clearly and with prevoicing. Subsequently, the original prevoicing of each related prevoiced item was replaced by 12, 6 or 0 periods of prevoicing (corresponding to 129, 64 or 0 ms of prevoicing for /b/ and to 127, 62 and 0 ms of prevoicing for /d/), in order to create the three different prevoicing conditions.

The first full period of prevoicing plus the lead-in (of 5 ms) of a natural token of the word *bus* /bʉs/ (‘bus’) was chosen as the first period of prevoicing for the two conditions with prevoicing for the items starting with a labial plosive. Similarly, the last prevoicing period of that same token of /bʉs/ always served as the last prevoicing period in these two conditions. The intervening prevoicing periods (10 or 4) were randomly chosen from the /bʉs/ token. The same procedure was applied to create the prevoicing 12 and prevoicing 6 conditions for the items starting with an alveolar plosive, but now the prevoicing periods were derived from a natural token of the word *dus* /dʉs/ (‘thus’). To control for any splicing effects, the prevoicing of each of the unrelated primes was also replaced by six periods of prevoicing.

		HF words	LF words	Nonwords (Exp 2 only)
PRIME	Prevoicing 12	*bloem* 'flower'	*beits* 'stain'	*breld*
	Prevoicing 6	*bloem* 'flower'	*beits* 'stain'	*breld*
	Prevoicing 0	*bloem* 'flower'	*beits* 'stain'	*breld*
	Unrelated	*baan* 'job'	*broche* 'brooch'	*biem*
TARGET	Experiment 1 (associative)	*roos* 'rose'	*verf* 'paint'	–
	Experiment 2 (identity)	*bloem* 'flower'	*beits* 'stain'	*breld*

Table 1: *Design of Experiments 1 (associative priming) and 2 (identity priming). For each combination of priming condition and prime frequency (including nonword primes) examples of a prime and target are given. Real words have their English translation in parentheses.*

Procedure

Primes were presented binaurally over headphones in a sound-damped booth. Immediately after the offset of the prime the visual target was presented in lower case on a computer screen. Subjects were instructed to listen to the word and then decide as quickly as possible whether the stimulus on the screen was a word or a non-word, by pressing one of two buttons. Four lists were constructed with priming condition counterbalanced across lists. Each subject therefore saw each target only once, preceded by one of the four possible primes for that item. Furthermore, the lists contained all fillers such that half of the targets were words and the other half non-words. Of the total of 320 pairs in a given list, 80 pairs (25%) were related.

After the associative priming experiment, all test items that were used as related primes were presented to the same listeners for identification of the initial phoneme. In addition to the 240 word tokens starting with a voiced plosive (/b/ or /d/), the identification task contained three repetitions of 80 distractor words starting with a voiceless plosive (/p/ or /t/). The items were blocked by place of articulation. Half of the subjects started with the labial plosives and half of the subject started with the alveolar plosives.

5.2 *Results and discussion*

The results of the phoneme identification task showed that, overall, 97% of the items starting with a voiced plosive were identified as voiced. One item appeared to be misrecorded and was therefore removed from all further analyses. Table 2 shows the percentage of voiced responses in each of the three prevoicing conditions for HF words and LF words separately.

		HF words	LF words	Nonwords
Experiment 1	Prevoicing 12	98.0	98.3	–
	Prevoicing 6	98.6	98.5	–
	Prevoicing 0	93.2	93.4	–
Experiment 2	Prevoicing 12	98.7	98.6	99.3
	Prevoicing 6	98.9	99.4	99.4
	Prevoicing 0	93.8	93.5	82.9

Table 2: *Percentage of voiced responses in the identification task of Experiments 1 and 2*

The proportions of voiced responses were converted through an arcsine transformation (Studebaker 1985) and submitted to repeated measures subjects (F1) and items (F2) analyses of variance (ANOVAs) with the factors frequency and prevoicing. There was a main effect of prevoicing ($F1(2,94) = 47.89$, $p < .001$; $F2(2,154) = 38.46$, $p < .001$). No other effects were significant. Tukey honestly significant difference (HSD) tests showed that the proportion of voiced responses to tokens without prevoicing was significantly lower than those to items with prevoicing (either 12 or 6 periods of prevoicing). Nevertheless, these tokens without prevoicing were in general still perceived as voiced. Note that all items starting with voiced plosives were words, which could have biased listeners to respond with the voiced category. Inspection of the RTs of the identification responses suggested that some of the responses were initiated even before the end of the prevoicing (in particular when the plosive started with 12 periods of prevoicing). Apparently, in some cases the presence of prevoicing alone provided sufficient information that the plosive was voiced. Since not all responses were initiated after the end of the prevoicing, it was not possible to correct for the length of the prevoicing. Therefore, there was no accurate way to analyze the RTs of the identification data in this experiment.

In the associative priming study the effect of the different prevoicing durations was investigated by measuring lexical decision RTs to the visual targets. RTs were measured from target onset and therefore there was no need to correct for differences in the duration of the prime as a result of the prevoicing manipulation. The mean latencies of correct lexical decisions to word targets are shown in Figure 2.

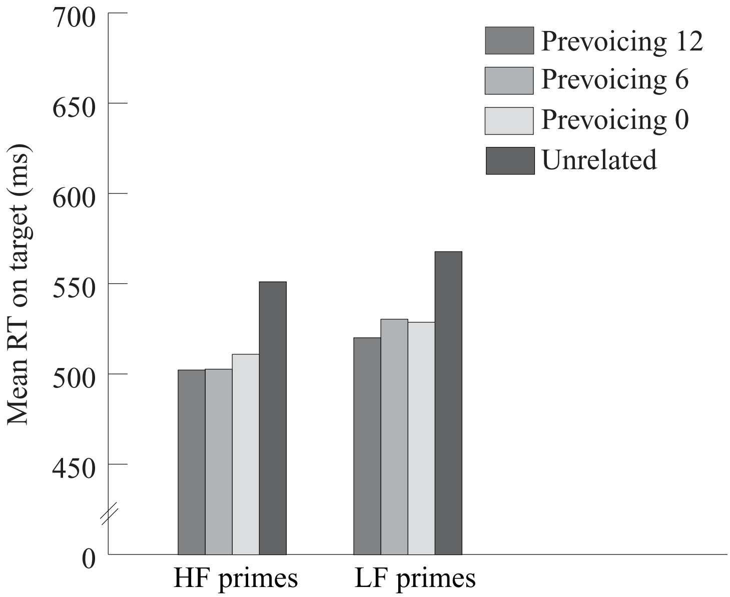

Figure 2. *Mean reaction times (RTs) to word targets preceded by high frequency (HF) and low frequency (LF) primes in each of the four priming conditions in Experiment 1 (associative priming).*

Subjects showed semantic facilitation, responding faster to targets preceded by semantically related primes than to targets preceded by unrelated primes. Repeated-measures subjects (F1) and items (F2) ANOVAs with prime type (12 periods, 6 periods, no prevoicing, unrelated), frequency (HF and LF), phoneme (/b/ and /d/) as factors showed significant effects of prime type: $F1(3,141) = 29.41$, $p < .001$; $F2(3,225) = 24.60$, $p < .001$, and of frequency: $F1(1,47) = 33.13$, $p < .001$; $F2(1,75) = 6.33$, $p < .05$. No other effects were significant. In addition, t-tests on the following three planned comparisons were carried out: prevoicing 12 – prevoicing 6, prevoicing 6 – unrelated, and prevoicing 0 – prevoicing 6. The outcomes of the two-tailed t-tests showed that the difference between the prevoicing 6 condition and the unrelated condition was significant ($t1(47) = –6.39$, $p < .001$; $t2(78) = –5.82$, $p < .001$), but that the other two differences were not significant. This indicates that lexical decisions were significantly faster when the target was preceded by a semantically related prime than when the target was preceded by a semantically unrelated prime, and that the lexical decisions latencies were not affected by the degree of prevoicing. There were also no differences among the error rates of the three prevoicing conditions.

The frequency effect indicated that RTs to targets preceded by a HF prime were faster than RTs to targets preceded by a LF prime (517 ms versus 537 ms). RTs were negatively correlated with target word frequency ($r(79) = –0.249$,

$p < 0.05$, two-tailed), but were not correlated with prime frequency, showing that the frequency effect on RTs was caused by target frequency, not prime frequency.

These results suggest that the three prevoicing variations tested here (12, 6 and 0 periods) do not influence lexical access. It is possible, however, that the VOT variation tested here does influence lexical access but that the associative priming task is not sensitive enough to measure an influence of such small acoustic differences. Another possibility is that the effect is too short-lived to be observed at an inter-stimulus interval of 0 ms. Therefore an identity priming experiment was carried out in which the visual target was presented earlier relative to the prime. The cross-modal version of this task, rather than the intra-modal version, was chosen to ensure that differences in the speed of the lexical decisions would reflect a difference in the degree of lexical activation rather than a difference in the degree of prelexical activation. This argument is in this case even more important since in the identity priming task the phonological overlap between prime and target is considerable, if not complete. This type of overlap can lead to non-lexical facilitation when prime and target are both presented auditorily (e.g., Slowiaczek, McQueen, Soltano & Lynch 2000). Furthermore, we know from the findings by Spinelli, McQueen & Cutler (2003) that the cross-modal identity priming task is sensitive to subtle variation in the initial phoneme.

6. *Experiment 2*

6.1 *Method*

Participants

Forty-eight subjects were paid to participate in this experiment. None had participated in the first experiment and none reported any hearing loss.

Materials

The same 40 HF words and 40 LF words of Experiment 1 were used in Experiment 2, but this time the visual target was the same word as the prime. For each target an unrelated prime was constructed that had the same number of syllables and the same initial phoneme as the related prime. There were also non-word primes. In addition to these items there were 200 filler pairs in which there was no relation between the prime and the target. They consisted of 40 non-word-non-word pairs, 80 non-word-word pairs and 80 word-non-word pairs. All materials came from the same recordings as in Experiment 1 and the VOT was manipulated in exactly the same way. The design was summarized in Table 1.

Procedure

The procedure was identical to that of Experiment 1 except that the visual target was presented 200 ms after the onset of the burst. As in Experiment 1, subjects were asked to perform a phoneme identification task on the test items after they had completed the lexical decision task. To shorten the identification phase, listeners only had to identify the initial phoneme of each related prime with the same amount of prevoicing as the one they had heard in the identity priming experi-

ment. Again, half of the items in the identification experiment consisted of distractors (this time words and non-words) starting with a /p/ or /t/.

6.2 *Results and discussion*

The results of the identification task indicated that 96% of the items starting with a voiced plosive were identified as voiced. Table 2 gives the mean percentage of voiced responses for each prevoicing condition, separately for HF words, LF words and non-words. The ANOVAs on the transformed proportions showed a significant effect of frequency ($F1(2,94) = 16.51$, $p < .001$; $F2(2,116) = 3.73$, $p < .05$), a significant effect of prevoicing ($F1(2,94) = 95.66$, $p < .001$; $F2(2,232) = 51.19$, $p < .001$) and a significant interaction between frequency and prevoicing ($F1(4,188) = 18.95$, $p < .001$; $F2(4,232) = 6.00$, $p < .001$. Tukey HSD tests showed that the proportion of voiced responses was higher for words (HF or LF) than for non-words and that, as in Experiment 1, tokens without prevoicing were less often identified as voiced than tokens with prevoicing. Furthermore, the interaction between frequency and prevoicing was due to the fact that the difference between tokens with and without prevoicing was larger in the non-words than in the HF or LF words. This confirms the suggestion which was made earlier, that the identification of voiced plosives without prevoicing was influenced by the lexical status of the item.

Figure 3 shows the mean RTs of the lexical decisions for the four priming conditions, plotted separately for the three target conditions. Since correct lexical decisions to the HF and LF targets involved “yes” decisions, while correct lexical decisions to the non-word targets involved “no” decisions, words and non-words were analyzed separately. In the analysis of the word targets there were significant effects of prime type: $F1(3,141) = 70.76$, $p < .001$; $F2(3,225) = 58.60$, $p < 001$, and frequency: $F1(1,47) = 324.26$, $p < 001$; $F2(1,75) = 102.41$, $p < 001$. There was also a significant interaction between prime type and frequency: $F1(3,141) = 6.50$, $p < .001$; $F2(3,225) = 5.38$, $p = .001$).

As in the previous experiment, t-tests on the following three planned comparisons were carried out: prevoicing 12 – prevoicing 6, prevoicing 6 – unrelated, and prevoicing 0 – prevoicing 6. Only one pairwise comparison was significant: the difference between the prevoicing 6 condition and the unrelated condition: $t1(47) = –9.80$, $p < .001$; $t2(78) = –8.68$, $p < .001$. This indicates that lexical decisions were significantly faster when targets were preceded by identical primes than when targets were preceded by unrelated primes, and that there was no difference in the degree of priming among the three prevoicing conditions.

The significant effect of frequency indicated that lexical decisions were slower to LF targets than to HF targets (632 ms versus 529 ms). Note that in this experiment related primes and targets were identical and therefore LF primes were followed by LF targets and HF primes by HF targets. The significant interaction between prime type and frequency was further inspected by performing planned t-tests for the three priming condition combinations for LF and HF primes separately. In both frequency groups, only the differences between the prevoicing 6 priming conditions and the unrelated priming conditions were significant.

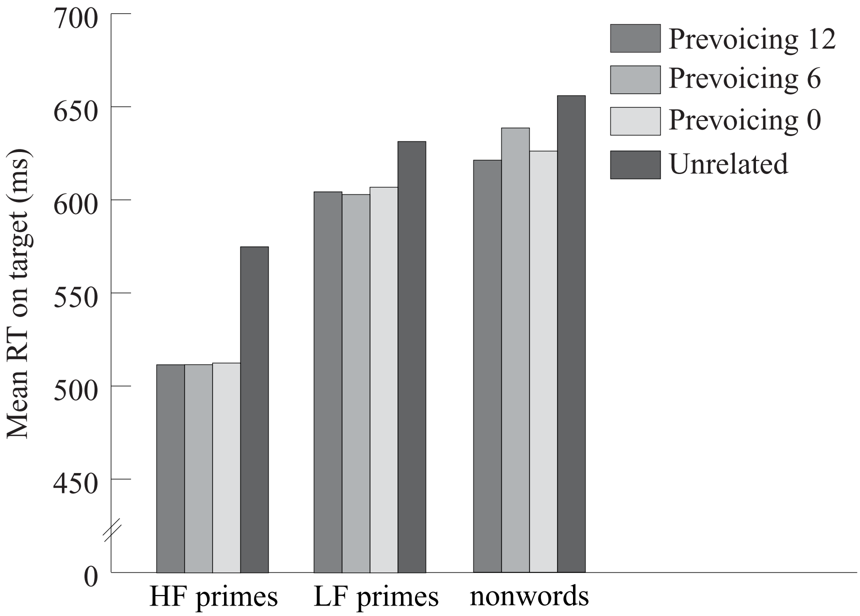

Figure 3: *Mean reaction times (RTs) to high frequency (HF) word targets, low frequency (LF) word targets and nonword targets in each of the four priming conditions in Experiment 2 (identity priming)*

Figure 3 also shows the mean RTs of the lexical decisions to non-word targets. For the non-words there was a significant effect of prime type: $F1(3,141) = 5.71$, $p = .001$; $F2(3,114) = 5.18$, $p < 0.01$. Nevertheless, the three planned t-tests showed that none of the pair wise comparisons were significant, indicating that the priming effect was not as robust as in real words. This suggests that the facilitation measured in an identity priming task is mainly due to activation at the lexical level rather than activation at the prelexical level.

The results of the identity priming experiment are comparable to the results of the associative priming experiment. Both experiments show facilitation in lexical decisions to words when targets are preceded by related primes relative to when preceded by unrelated primes. But the VOT manipulations did not affect the degree of facilitation. It is possible, however, that the differences in prevoicing in these experiments were too small to be detectable for the listeners. Even though oscillograms of the stimuli clearly show that they differ in the degree of prevoicing, this does not necessarily mean that listeners can hear these differences. If they cannot hear these differences, it would not be very surprising that this type of variation does not influence lexical access. To test this, a third experiment was conducted in which listeners had to discriminate between the primes with different degrees of prevoicing.

7. *Experiment 3*

7.1 *Method*

Participants

Ten subjects participated. None reported any hearing loss and none had taken part in the first two experiments.

Materials

The materials used in this experiment consisted of the 120 test items of Experiment 2 (40 HF words, 40 LF words and 40 non-words). For each item all three prevoicing versions were used (12 periods of prevoicing, 6 periods of prevoicing and no prevoicing). For each item 6 pairs were constructed in such a way that all combinations of prevoicing (prev) appeared: prev 12 – prev 12, prev 6 – prev 6, prev 0 – prev 0 (the “same” pairs) and prev 12 – prev 0, prev 6 – prev 0 and prev 12 – prev 6 (the “different” pairs). The order of items within the “different” pairs was balanced. In total there were 720 pairs.

Procedure

All pairs were presented auditorily in a sound-damped booth in random order. The ISI within a trial was 300 ms and the interval between the offset of a trial and the onset of the next trial was 2000 ms. Subjects were asked to listen carefully to the two items while concentrating on the beginning of the initial sounds and to decide whether the two items were the same or different, by pressing the appropriate button. Before the real experiment started they heard 12 pairs that were different. They had been told beforehand that there was a difference in the initial phoneme between the two items of each pair. After that there was a training session of 24 pairs prior to the main experiment session.

7.2 *Results and discussion*

Following Macmillan & Creelman (1991), d' was calculated for each subject for each prevoicing combination. This is a measure for the listeners’ sensitivity to discriminate two stimuli from each other by taking into account both the proportion of hits and the proportion of false alarms. When d's differ from zero this indicates that listeners performed above chance. Moderate performance implies that d' is near unity (Macmillan & Creelman 1991).

A one-way ANOVA on the d's indicated that there was a main effect of prevoicing combination: $F(2,20) = 24.29$, $p < .001$. A Tukey HSD test showed that the combination prev 12 – prev 0 differed significantly from the combinations prev 6 – prev 0 and prev 12 – prev 6, but that the difference between the combinations prev 6 – prev 0 and prev 12 – prev 6 was not significant. Thus it was easier to discriminate between two members which differed 12 periods of prevoicing from each other than to discriminate between two members which differed only in 6 periods from each other. Nevertheless, all d's differed significantly from zero (prev 12 – prev 0: $t(10) = 8.20$, $p < .001$; prev 6 – prev 0: $t(10) = 7.11$, $p < .001$; prev 12 – prev 6: $t(10) = 4.34$, $p = .001$). This indicates that listeners performed

above chance and could thus discriminate among all three prevoicing durations. The d's of the pairs involving 0 periods of prevoicing also differed significantly from unity (prev 12 – prev 0: $t(10) = 5.10$, $p < .001$; prev 6 – prev 0: $t(10) = 2.92$, $p < .05$). This suggests that the difference between 12 and 6 periods of prevoicing was the most difficult to detect.

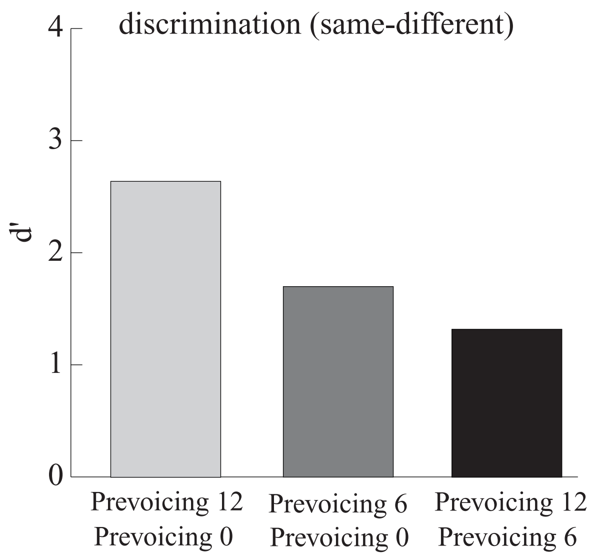

Figure 4: *Mean d's for the three combinations of prevoicing in Experiment 3 (discrimination).*

8. *The influence of voiceless lexical competitors on the effect of prevoicing differences*

The two priming experiments reported here investigated the influence of prevoicing variation on lexical access and its interaction with the frequency of the lexical candidates. Both experiments showed a clear priming effect for words. In the associative priming task, listeners were faster to decide that the visual target such as *roos* ('rose') was a word when its was preceded by a semantically related prime such as *bloem* ('flower') than when it was preceded by a semantically unrelated prime such as *baan* ('job'). In the identity priming task, lexical decisions to word targets such as *bloem* were faster when the target was preceded by a prime which was identical to the target (in this case the auditory version of *bloem*) than when the target was preceded by unrelated primes, such as *baan* ('job'). For the non-words no substantial priming effect was found. Furthermore, both experiments showed no difference among primes with 12, 6 or 0 periods of prevoicing.

The absence of an effect of prevoicing duration (12 periods of prevoicing versus 6 periods of prevoicing) was expected. Recall that van Alphen & Smits (2004) found that in Dutch the amount of prevoicing appears to be uninformative to the listener. All tokens which were produced with prevoicing were unambiguously

identified as voiced, regardless of the exact amount of prevoicing. The primary cue to the perception of [+voice] appeared to be the presence of prevoicing, rather than the duration of prevoicing. Therefore, we predicted that variation in the amount of prevoicing (12 versus 6 periods) would not affect lexical access.

The absence of an effect of the deletion of prevoicing, however, seems puzzling. Van Alphen and Smits showed that when prevoicing was absent, the probability that the token was voiced decreased. Nevertheless, the majority of the voiced plosives without prevoicing were still perceived as voiced. This is in line with the present identification results: although all tokens in these experiments were in general perceived as being voiced, the percentage of voiced responses was lower for tokens with no prevoicing than for tokens with 12 or 6 periods of prevoicing. As mentioned earlier, several studies have shown that lexical activation is sensitive to fine-grained acoustic information, suggesting that information flows continuously from a prelexical level of processing to the lexical level. Based on these findings one would expect that the deletion of prevoicing would affect the degree of activation of lexical candidates starting with voiced plosives.

It is also the case, however, that prevoicing deletion does not result in unnatural or rare tokens. Prevoicing is frequently absent in naturally produced tokens of voiced plosives. As a result, Dutch listeners have often encountered words starting with plosives without prevoicing that should have started with voiced plosives (e.g., hearing *bloem* without prevoicing). Therefore, Dutch listeners might have learned that a plosive without prevoicing could still be voiced. This can explain why no effects of prevoicing deletion were found in the current priming studies. However, since in natural speech most plosives without prevoicing are actually voiceless, listeners should not ignore the presence or absence of prevoicing. Tokens without prevoicing should thus activate both voiced and voiceless prelexical representations, which in turn should activate lexical candidates starting with voiced plosives and lexical candidate starting with voiceless plosives. Note that none of the words in the present study had a voiceless word competitor. That is, for all words, changing the voicing category of the initial voiced plosive from voiced to voiceless resulted in non-words (e.g., *ploem* is not a Dutch word). Therefore, there were no voiceless lexical candidates which could seriously compete with the voiced word candidates. If it is indeed the case that items starting with voiced plosives without prevoicing activate both voiced and voiceless lexical candidates, one would expect to find effects of prevoicing deletion when primes are used which have a voiceless word candidate that could be activated.

Van Alphen & McQueen (2006) therefore investigated the influence of the competitor environment on the effect of prevoicing variation. They ran two cross-modal identity priming experiments similar to Experiment 2 of the present study, but, instead of the frequency conditions, they constructed four different lexical status conditions. The first condition, referred to as the Blue condition, contained word primes starting with voiced plosives which had no voiceless word competitor, for example *blauw* (*blauw* means ‘blue’ and *plauw* is not a word of Dutch). This condition is equivalent to that tested in the present Experiment 2. The second condition, referred to as the Bear condition, contained word primes starting with

voiced plosives with voiceless word competitors, for example *beer* (*beer* means 'bear' and *peer* means 'pear'). The third condition, the Blem condition, like the non-word condition in Experiment 2, contained non-word primes starting with voiced plosives without voiceless word competitors, for example *blem* (neither *blem* or *plem* is a word of Dutch). The final condition, the Brince condition, contained non-word primes starting with voiced plosives which had a voiceless word competitor, for example *brins* (*brins* is not a word of Dutch and *prins* means 'prince').

In both experiments five priming conditions were used. In addition to the three prevoicing conditions (prevoicing 12, prevoicing 6, prevoicing 0) and the unrelated priming condition which were also used in the present study, a voiceless priming condition was constructed which contained natural recordings of the voiceless word and non-word counterparts of the voiced primes. This voiceless priming condition (e.g., the prime *peer*) served together with the voiced priming condition (e.g., the prime *beer* with 6 periods of prevoicing) as reference conditions for the condition with voiced primes without prevoicing. The combination of five priming conditions and four lexical status conditions resulted in 20 different conditions in each experiment.

The difference between the two priming experiments was the nature of the target. In the first experiment the items starting with voiced plosives served as targets, while in the second experiment the voiceless counterparts of the voiced items served as targets. For example, in the Bear condition, in the first experiment the target was beer and in the second experiment it was peer. In this way the degree of activation of both the voiced and voiceless lexical candidates (e.g., *beer* and *peer*) could be measured.

The results showed clear priming effects when prime and target were identical. Furthermore, the RT patterns showed that when prime and target differed only in the phonological voicing of the initial phoneme (for example, the prime was *peer* and the target was *beer*) no facilitatory effect was found. As in the present experiments, there was never an RT difference between the effect of a prime with 12 periods of prevoicing and that of a prime with 6 periods of prevoicing. As in the present experiments, there was also no effect of prevoicing deletion when the voiced prime had no voiceless word competitor. Crucially, however, when the voiced prime did have a voiceless word competitor, effects of prevoicing deletion were found. For example, when word targets such as *peer* were preceded by voiced primes without prevoicing (*beer* without prevoicing), lexical decisions to targets were faster in comparison to the same targets preceded by voiced primes with prevoicing (e.g., *beer* with 6 periods of prevoicing), but slower in comparison to the same targets preceded by voiceless primes (e.g., *peer*). Similarly, when a non-word target such as *brins* was preceded by voiced primes without prevoicing (e.g., *brins* without prevoicing), lexical decisions (in this case "no" decisions) were slower in comparison to decisions to the same targets preceded by voiced primes with prevoicing (e.g., *brins* with 6 periods of prevoicing) and faster in comparison to these targets preceded by voiceless primes (e.g., *prins*). For a de-

tailed description of the patterns found in all conditions see van Alphen & McQueen (2006).

These results suggest that items starting with voiced plosives without prevoicing significantly activate both lexical candidates starting with voiced plosives and lexical candidates starting with voiceless plosives. Items with prevoicing do only significantly activate lexical candidates starting with voiced plosives. In none of the lexical status conditions an effect of the difference between 12 and 6 periods of prevoicing was found. It thus appears that the recognition system is more sensitive to variation in the speech signal that is more important for lexical distinctions. The presence or absence of prevoicing appears to be the primary cue for the voicing distinction in Dutch while variation in the exact duration of prevoicing is not very important. As a result, a difference between the presence and absence of prevoicing (6 versus 0 periods of prevoicing) influences lexical access more strongly than a difference in the amount of prevoicing (12 versus 6 periods of prevoicing). Effects of the absence of prevoicing, which is relevant for word recognition, were only observed when there was a voiceless lexical candidate. When there was no such candidate, the voiced word candidate was the only plausible lexical hypothesis and could easily win the competition with all other candidates, even when there was no prevoicing.

9. *Conclusions*

In this article I have focused on the phonological voicing distinction in Dutch initial plosives. The phonological distinction between [b] and [d] on the one hand and [p] and [t] on the other hand, is straightforward: the former are voiced and the latter are voiceless. The phonetic realization of this distinction in Dutch, however, is less straightforward. Voiced plosives are said to be produced with voicing during the closure (i.e., with a negative VOT) while voiceless plosives are produced without voicing during the closure but with little or no aspiration (i.e., with a positive VOT). The study on the occurrence of prevoicing in Dutch revealed that a considerable proportion of voiced plosives (25%) were produced without prevoicing. When the aerodynamic circumstances made it more difficult to produce vocal vibration, prevoicing was often absent. Nevertheless, these tokens could still be perceived as voiced, provided that the remaining acoustic cues were in favour of a voiced plosive. This last condition, however, was not always met. As a result, some of the voiced tokens without prevoicing were perceived as voiceless. In contrast, all tokens produced with prevoicing were perceived as voiced.

The presence of prevoicing is thus a very strong cue to the perception of plosives as voiced, but is nevertheless not always realized by speakers when producing voiced plosives. This is an intriguing paradox. How does the speech perception system treat the absence of prevoicing? On the one hand, listeners have learned that the absence of prevoicing strongly signals that the token is voiceless; on the other hand, listeners have often encountered words with plosives without prevoicing which appeared to be voiced. The identification results showed that the absence of prevoicing influenced the proportion of voiced responses. Although the majority of the tokens without prevoicing were perceived as voiced, some lis-

teners perceived some of these tokens as voiceless. What consequences does this have for the recognition of words starting with voiced plosives without prevoicing? Is a word like *bloem* still recognized when it is produced without prevoicing, or is it sometimes recognized as *ploem*? Even if it is correctly recognized, the absence of prevoicing could still have affected the recognition process. It is possible that words starting with plosives without prevoicing are more difficult to recognize than words with prevoicing. In order to fully understand the role of prevoicing in perception it is therefore important to also include word recognition.

Two priming experiments were presented which investigated the effects of prevoicing deletion on lexical activation. The difference between the presence and absence of prevoicing was contrasted with a difference in the amount of present prevoicing. Both prevoicing differences were of the same size and fell within the natural range of prevoicing variation. The prediction was that these two types of prevoicing variation differ, however, in their informational value. While the presence or absence or prevoicing is relevant to the voicing distinction, the exact duration of the prevoicing is not. The hypothesis was that only acoustic detail which would help to distinguish between two phoneme classes, and thus between lexical candidates, would affect lexical activation, while irrelevant acoustic detail would be normalized away at the prelexical level. Therefore, the difference involving the presence or absence of prevoicing was expected to affect lexical activation, while the difference between 12 and 6 periods of prevoicing was not.

The results suggested that neither of the two differences in prevoicing had an effect on the degree of lexical activation. I argued that the absence of an effect of the deletion of prevoicing could be explained by the fact that prevoicing is frequently absent in Dutch. Dutch listeners have often encountered words starting with plosives without prevoicing that should have started with voiced plosives (e.g., hearing *bloem* without prevoicing). Therefore, they might have learned that a plosive without prevoicing could still be voiced. When the words starting with voiced plosives had no matching voiceless word competitor, as was true for all primes in the two present priming experiments, the lexical candidate starting with the voiced plosive was considered to be the only plausible lexical hypothesis when listeners heard these words without prevoicing. This argument was strengthened by the results of two different priming experiments in which the competitor environment of the words with initial voiced plosives was manipulated (van Alphen & McQueen 2006). When the primes had a voiceless word competitor, an effect of prevoicing deletion was observed. But there was never an effect of the difference between 12 and 6 periods of prevoicing.

The results of these priming experiments show that word recognition is more sensitive to phonetic detail that is more important for phonemic distinctions (and thus for lexical distinctions). It also shows the robustness of the word recognition system and the influence of the lexical competitor environment. When there is no voiceless word competitor, the recognition system can easily recover from effects of prevoicing deletion, probably due to the fact that this type of variation naturally occurs in Dutch. Only when there is a voiceless word competitor can prevoicing deletion substantially affect the recognition process.

By combining the results of production and perception experiments, including experiments involving word recognition, I aimed to give more insight into the voicing distinction in Dutch initial plosives and the role of prevoicing. In particular, I intended to show that the distinction between voiced and voiceless plosives is less straightforward than one might expect on the basis of the phonological description of these sounds. It appears that the recognition system does not make a simple binary distinction between voiced and voiceless plosives (such as [+voiced] and [–voiced]), but that there are different degrees of voicing. The phonetic realization of a plosive determines the probability that the plosive is voiced. Of all acoustic properties, prevoicing appears to be one of the most important cues affecting this probability. Nevertheless, voiced plosives are frequently produced without prevoicing. This not only affects the role that prevoicing plays in the perception of plosives as voiced or voiceless, but also the way in which the word recognition system treats variation in prevoicing.

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Dutch Regressive Voicing Assimilation as a 'Low Level Phonetic Process'
Acoustic Evidence

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This paper investigates the behaviour of a number of acoustic cues to phonological [voice] in Dutch word-final /ps/ sequences. It reports measurements on elicited productions of such clusters before phonologically voiced and voiceless plosives, the labial nasal /m/, the glottal consonant /h/ and lexical vowels. The results of this experiment provide evidence that regressive voice assimilation (RVA) occurs in /ps/ clusters before [+voice] plosives, contradicting claims in some of the literature that obstruent + fricative sequences are exempt from RVA. The behaviour of the individual cues to [voice] observed here also suggests that Dutch regressive voicing assimilation is a 'low level' coarticulatory process rather than a rule manipulating lexical phonological structure.

1. *Introduction*

Phonological accounts of Dutch regressive voicing assimilation (RVA) tend to regard the process as *asymmetric* in more than one respect. First, the obstruents targeted by this assimilation rule are subject to an independent rule of final laryngeal neutralization or 'final devoicing', which (on most accounts) means that voicing assimilation does not occur, or is rendered vacuous, before phonologically [–voice] obstruents. Laryngeal neutralization applies across the board in word-final environments and consequently assimilation does not have to be invoked to account for the voiceless realization of the final obstruent of underlying /zɑnd/ in a compound such as [zɑntplaːt] 'sandbar'. Instead, this realization can be attributed to the same constraint or rule that makes /zɑnd/ + /loːpər/, 'hourglass' surface as [zɑntloːpər]. An SPE-style linear version of this rule appears in (1a) below (cf. (1) in Zonneveld, this volume).

In other words, only [+voice] obstruents are commonly regarded as being capable of triggering (observable) RVA in the phonology of Dutch. This means that the relevant rule or constraint can be formulated with reference to [+voice] only, as in (1b), although a symmetric version produces exactly the same result (cf. rule (2) in Zonneveld, this volume).

(1) a. Final devoicing
$[–son] \rightarrow [–voice]$ / __ #

b. Voicing assimilation

$$[-\text{son}] \rightarrow [+\text{voice}] \;/\; \_\_ \begin{bmatrix} -\text{son} \\ -\text{cont} \\ +\text{voice} \end{bmatrix}$$

c. Fricative devoicing

$$[-\text{son}, +\text{cont}] \rightarrow [-\text{voice}] \;/\; [-\text{son}] \; \_\_$$

Second, virtually all descriptions of the language agree that among Dutch [+voice] obstruents only the *plosives* trigger regressive voicing assimilation: the [+voice] fricatives /v, z/, and in southern varieties /ɣ/, are devoiced when preceded by an obstruent and fail to trigger voicing assimilation in preceding obstruents. Thus, whereas the word-final stop of /zɑnd/ may be voiced through RVA in for instance [zɑndbɑk] ‘sandbox’, the medial cluster in /zɑnd zɑk/ ‘sandbag’, surfaces as entirely voiceless: [zɑntsɑk] (or perhaps [zɑntz̥ɑk]). (1c) represents a linear version of the fricative devoicing rule (cf. (3) in Zonneveld, this volume).

Under this analysis, then, Dutch regressive voicing assimilation is (trivially) asymmetric with respect to the feature [voice] (or some formal equivalent) in that it is only triggered by one of the 2 possible values, and it is asymmetric with respect to manner of articulation because it can only be triggered by plosives.

In light of the second asymmetry, it is perhaps surprising that relatively few accounts of Dutch RVA consider the behaviour of clusters composed of word-final stop + fricative combinations followed by [+voice] stops, as in, e.g., /rɛɪks/ + /daːldər/ ‘Dfl 2.50 coin (proper name)’ or /fiːts/ + /bɛl/ ‘bicycle bell’. In such sequences, regressive voicing assimilation and fricative devoicing clash in the sense that the former requires at least the medial fricative to be voiced, whereas the latter demands that the medial fricative be voiceless. Thus, the behaviour of obstruent + fricative + voiced plosive clusters would seem to provide some useful clues to the proper formulation, and/or ordering (or ranking) of the formal rules in (1) above.

Brink (1975) is one of the few authors to discuss this issue within a generative phonological framework. Citing earlier work on Dutch, he states categorically that no RVA takes place in obstruent + fricative + [+voice] plosive sequences. Brink claims that words such as /fiːts/ + /bɛl/ can be pronounced with a phonetically prevoiced [+voice] plosive, as in [fiːtsbɛl], or with a (partially) devoiced [+voice] plosive as in [fiːtsb̥ɛl], but are never realized with any voicing in the obstruents preceding obstruents: *[fiːtzbɛl], *[fiːdzbɛl]. This view is echoed by Cammenga & van Reenen (1980), who criticize the account of Dutch obstruent voicing in Booij (1981) for predicting RVA in this type of cluster. On the basis of these claims, rule orderings or constraint rankings would have to give priority to fricative devoicing (1c) over voicing assimilation (1b).

This paper discusses a production experiment that was designed to test the above assertions by Brink (1975) and Cammenga & van Reenen (1980). Four native speakers of Dutch were asked to produce word-final /p/ + /s/ sequences in a range of contexts. Their productions of these clusters were then examined with

respect to a number of known acoustic correlates of [voice], including phonetic voicing and segmental durations. The results of this experiment contradict the claim that no assimilation occurs in stop + fricative + stop sequences. In particular, clear differences in phonetic voicing between /ps/ clusters preceding [–voice] and [+voice] plosives indicate that, at least in production, these clusters are subject to regressive assimilation of voice.

The implications of the experimental data reported below are potentially more far-reaching than this, however, in that they cast doubt on any model of Dutch RVA constructed along the lines of (1) above. Clusters of /p/ + /s/ followed by the [–voice] plosives /p, t/, the bilabial nasal /m/, and [+voice] /b, d/ appear to exhibit a three-way voicing contrast which suggests that Dutch regressive voicing assimilation is not asymmetric with regard to [voice] as often assumed, but behaves symmetrically, with nasals (and other sonorant consonants) acting as an 'intermediate' context between [+voice] and [–voice] plosives.

This finding and additional observations concerning the behaviour of /p/ + /s/ clusters before word-initial /h/ and lexical vowels might be accounted for in a drastically revised version of (1), but the nature of the effects involved as well as considerations of economy point to an account of Dutch RVA along the lines of proposals in Ernestus (2000) as the anticipatory coarticulation of laryngeal gestures.

2. *Methods*

2.1 *Subjects*

Subjects were 4 native speakers of Dutch aged between 21 and 45 at the time of recording. Two of the subjects were male (MJ1 and GBP3) and two were female (ER2 and LB4). None of the subjects had a history of speech or hearing impairment. They were not paid for their participation in the experiment. All speakers were residents of the town of Groningen at the time of recording, but spoke varieties of Dutch which can be roughly described as standard with minor (northern and western) local features (see further section 3.1 below).

2.2 *Materials*

The stimuli for this experiment consisted of clusters combining an initial /p/ C_1, and a medial /s/ C_2 followed by a /p, t, b, d, m, h/ C_3 or an unreduced lexical vowel (/V/), which is usually preceded by a [ʔ] in Dutch.[1] Although there is evidence that final laryngeal neutralization is phonetically complete in Dutch (Baumann 1995), C_1 obstruents were consistently /p/ and orthographic <p>, to avoid any potential bias due to spelling pronunciations or other incomplete neutralization effects.[2]

C_1s were embedded in a noun (N_1) representing a proper name. N_1s consisted of a single syllable that had the long low unrounded vowel /aː/ for its nucleus; this vowel is referred to as V_1 in the discussion below. The medial /s/ always represented an adjectival marker, as in /kaːp/ + /s/, 'of, from, pertaining to the Cape' or a possessive marker as in /jaːp/ + /s/, 'belonging to Jaap'.[3] The carrier words (N_2)

for C_3 were disyllabic nouns with an initial lexical stress. C_3 always preceded a long vowel or (phonotactically long) diphthong. The carrier words (N_2) for C_3 were disyllabic nouns with an initial lexical stress. The N_1+ N_2 collocations were further embedded in carrier sentences designed to attract a contrastive nuclear accent on N_2. Some sample stimuli (orthographic and phonological representations) appear in (2). Target clusters are underlined.

(2) Sample stimuli

a.

< Het	was	Jaaps	tunnel	die	onder	water	stond,	niet	zijn	kelder>
/ hɛt	ʋɑs	jaːps	tʏnəl	di	ɔndər	ʋaːtər	stɔnd	nit	zən	kɛldər/
It	was	Jaap's	tunnel	that	under	water	stood	not	his	basement

'It is Jaap's tunnel that was flooded, not his basement'

b.

<Het	was	een	Kaaps	meisje	dat	de	hoofdsprijs	won	niet	een	Kaaps	jongetje
/ hɛt	ʋɑs	ən	kaːps	mɛisjə	dɑt	də	hoːvdprɛis	ʋɔn	nit	ən	kaːps	jɔŋətjə
It	was	a	Cape	girl	who	the	head-prize	won	not	a	Cape	boy

'It was a little girl from the Cape who won the first prize, not a little boy from the Cape'

2.3 *Procedure*

The stimuli were presented to the subjects in a quasi-randomized order to avoid consecutive stimuli with identical consonant clusters. The subjects were asked to read the list of stimulus sentences 3 times. For the first, *Normal* reading, they were asked to read the stimulus items at a self-selected comfortable rate. In an attempt to simulate a noisy environment, the subjects were then fitted with sound-treated headphones conveying a 80 dB white noise signal (a noise level roughly comparable to that on a moving city bus) for the second reading, and asked to speak in such a way that they could understand their own speech. The aim of impoverishing the subjects' auditory feedback was to elicit a more hyperarticulated speech variety that is sometimes referred to as the *Lombard reflex* (Lombard 1910; see Junqua 1996 for an overview). For the third, *Fast*, reading, subjects were asked to read the stimulus items as fast as possible in order to create a bias to more hypoarticulated speech. Data concerning the speech rate variation that this design was intended to elicit are discussed in chapter 7 of Jansen (2004), but the effects in question are irrelevant for present purposes, and consequently all data reported below are pooled across reading tasks.

During each of the three readings subjects were asked to repeat an item if they produced a hesitation or speech error that was clearly audible to the experimenter and which affected the target cluster. In total, 1 (C_1 = /p/, C_2 = /s/) * 7 (C_3) * 10 (stimuli) * 3 (conditions) * 4 (speakers) = 840 utterances were recorded. Recordings were made onto minidisk in a sound-proofed room using a Brüel and Kjær condenser microphone (Type 4165) and measuring amplifier (Type 2609), and digitized at 22.5 kHz. Segmentation and acoustic measurements were carried out using the signal analysis package PRAAT (version 3.9). 31 utterances had to be discarded because they contained a pause between C_2 and C_3 or small speech errors, leaving 809 utterances for segmentation and analysis.

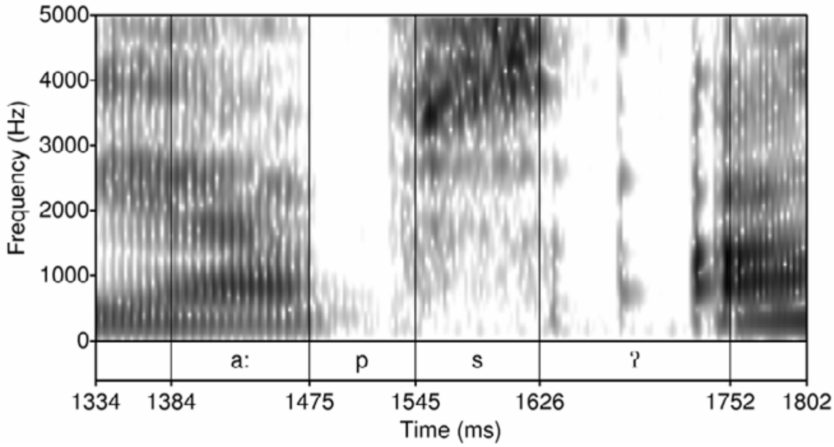

Figure 1: *Sample segmentation of glottal stop preceded by /ps/. Broad band spectrogram of a /ps/ + [ʔ] cluster: subject = ER2, condition = Normal*

Segment boundaries were determined by visual inspection of waveforms and broadband spectrograms based on Fast Fourier Transforms (*FFT*) on a 5 ms Gaussian window (spectrogram bandwidth 260 Hz). The boundary between a vowel and a following plosive C_1 was placed where there was an abrupt change in the higher frequency energy, as illustrated by Figure 1. The boundary between the C_1 plosive and the following /s/ was placed at the end of the release burst of the plosive, where this could be reliably identified as distinct from the frication noise of the fricative. In most cases, however it was impossible to segment the release burst from the fricative, and the boundary between C_1 plosive and /s/ was placed at the end of the closure stage of the former. The offset of the C_2 fricative was defined as the offset of frication noise. A glottal stop was marked as such if there was evidence of irregular glottal pulsing in the signal (this was virtually always the case): for an example, see Figure 1.

The measurements that were made on the basis of the hand-segmented speech samples, as well as the relevant derived measures are listed in Table 1, ordered by speech segment. All measures relevant to the $C_1 + C_2$ cluster and C_3 plosives are known phonetic correlates of [voice] in Dutch (e.g., Slis & Cohen 1969) and therefore potentially subject to the effects of RVA. Note that all measurements in the column for $C_1 + C_2$ were performed twice, that is, for /p/ and /s/ individually. Finally, the first measurement point for F_0 was placed at 10 ms after the onset of post-release voicing for plosives.

Segment			
V_1	$C_1 + C_2$	C_3	V_2
(a) Duration	(d) Duration	(g) VOT (stops)	(j) F_0 10-50 ms after C_3 release (stops, /m/)
(b) F_0 50-10 ms before C_1 onset	(e) Voicing duration	(h) Duration of initial voiceless period (/h/)	
(c) F_1 50-10 ms before C_1 onset	(f) Voicing ratio	(i) F_0 10-50 ms after the onset of voicing(/h/)	

Table 1: *Acoustic measurements and derived measures*

3. *Results*

3.1 *Phonetic features of C_3 plosives*

Unlike western and southern varieties of Dutch, the local varieties of the province of Groningen, where all of the subjects were resident at the time of recording, realize [–voice] stops as voiceless aspirated in word-initial and pre-stress medial contexts. This raises the possibility that the dialects in question produce [+voice] stops with a zero to short lag VOT rather than prevoicing, at least utterance initially and following other obstruents, and thus that they possess a VOT contrast along the lines of (standard varieties of) English and German (unfortunately I am not aware of any instrumental evidence that could settle this issue). Given that the presence of prevoicing appears to be a prerequisite for [+stops] to be able to trigger RVA (Kohler 1979, Jansen, 2004) it is important to assess the phonetic realization of the plosives in C_3 position before considering their effects on preceding obstruents.

The histograms in Figure 2 depict the frequency distributions of the VOT values for [–voice] /p, t/ and [+voice] /b, d/ in C_3 position. The left pane of this figure shows how the majority of VOT values for the [–voice] plosives falls within the 0-35 ms range that is usually labelled as *short lag* (91% of tokens ≤ 30 ms). The mean VOT for /p, t/ is 16 ms with a 9 ms standard deviation.

The right pane of Figure 2 shows a bimodal distribution of VOT values for /b, d/, with a first peak well within the prevoiced range between –100 ms and –50 ms, and a second peak in the short lag (> 0 ms) range. The overall mean VOT for /b, d/ is –54 ms (standard deviation 45 ms), whilst the mean for tokens in the prevoiced range (VOT < 0 ms) is –71 ms (standard deviation 33 ms). There is some interspeaker variation in the production of fully voiceless (VOT > 0 ms) [+voice] plosives: speakers MJ1 (19/57 tokens, 33%), and ER2 (19/60 tokens, 32%) show a somewhat stronger tendency to devoicing than speakers GBP3 (4/58 tokens, 7%) or LB4 (9/58 tokens, 16%). However, the overall proportion of devoiced productions of /b, d/ found here (51/233 tokens, 22%) seems roughly

equivalent to the 25% devoicing rate for Dutch word-initial /b, d/ reported by van Alphen (this volume).

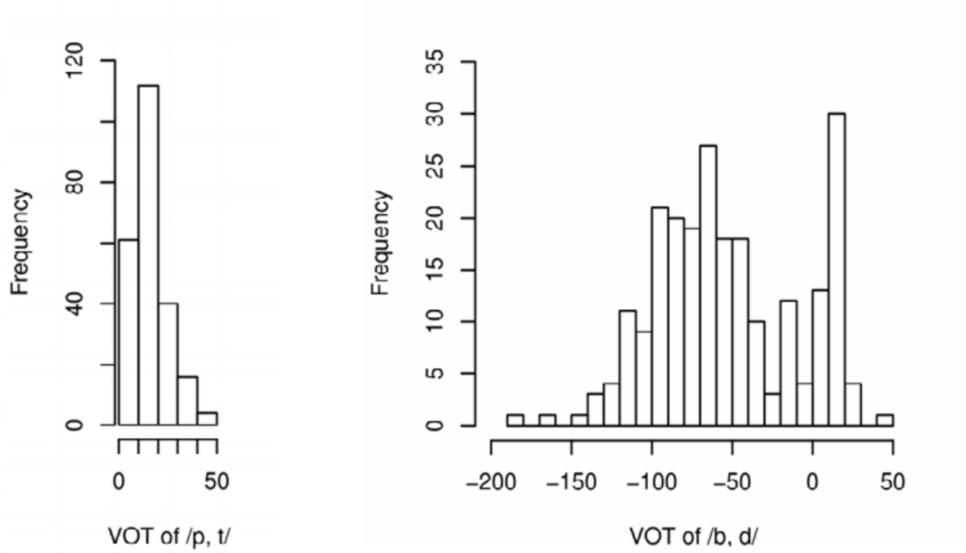

Figure 2: *Histograms of the VOT of C_3 plosives. Left panel: /p, t/; right panel: /b, d/*

Figure 3 depicts the mean F_0 trajectories during the first 50 ms following the onset of post-release voicing for [±voice] plosives (female speakers only). The mean F_0 trajectory following /m/ is included for comparative purposes. These trajectories and the highly similar results for the 2 male speakers suggest that the 4 speakers investigated here use F_0 perturbations as well as differences in VOT to

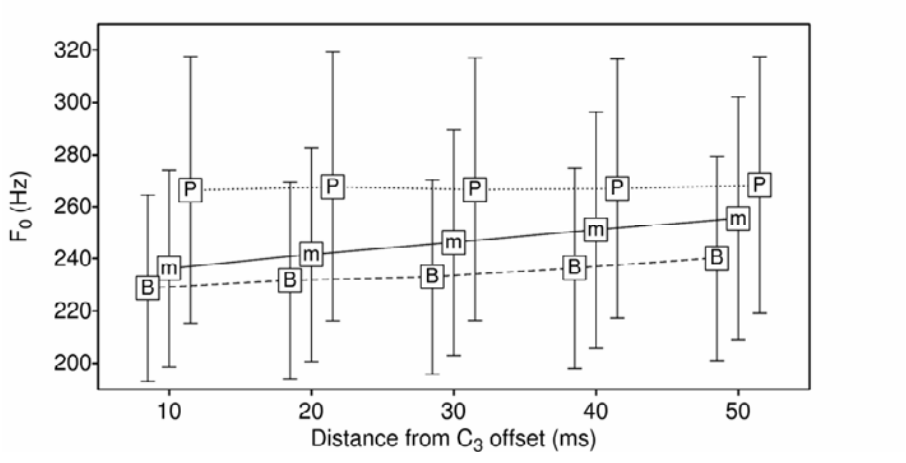

Figure 3: *F_0 (Hz) 10-50 ms into the vowel following C_3, for female speakers only.*
P represents /p, t/; B signifies /b, d/. Clusters ending in /h/ and /V/ excluded.
Error bars represent the mean ±1 standard deviation

cue [voice] contrast in word-initial plosives. At 10 ms into the voiced portion of the following vowel the difference in F_0 between [–voice] and [+voice] stops is 44 Hz (274 vs. 230 Hz) for the female speakers and 31 Hz (214 vs. 183 Hz) for the male subjects. These values do not appear to be exceptional in light of data reported elsewhere in the literature: for example Löfqvist et al. (1989) report a 27 Hz difference at post-release voicing onset for their male Dutch subject.

A final point of interest regarding Figure 3 is that the mean F_0 values following the baseline C_3 consonant/m/ appear to pattern with those for [+voice] /b, d/, rather than with the values found after [–voice] plosives or halfway between [+voice] and [–voice] plosives. A similar pattern has been observed for English by e.g., House & Fairbanks (1953) and Jansen (2004).

A one-way ANOVA for C_3 laryngeal specification (/p, t/ vs. /b, d/ vs. /m/) on the F_0 values at 10 ms into the following vowel (female speakers only, clusters ending in /h, V/ excluded) shows a highly significant effect: $F(1{,}298) = 31.55$, $p < .001$. Tukey and Scheffe post-hoc tests show that the [–voice] stops are distinct from both the [+voice] stops and sonorant /m/ ($p < .001$ for all pairwise comparisons), whilst the means for the latter 2 groups are not significantly different.

In sum, it seems safe to infer that the 4 subjects on whose speech this study is based employ VOT and F_0 microprosody to signal the [voice] contrast in word-initial plosives in broadly similar fashion to speakers of (standard) Dutch investigated elsewhere in the literature.

3.2 *C_1 + C_2 voicing*

Phonetic voicing is a cue to phonological [voice] word initially and medially in Dutch, and it therefore seems appropriate to use the amounts of voicing found in obstruents (potentially) targeted by the process as a measure of RVA. Note in this regard that the instrumental study by Slis (1986) uses phonetic voicing as the key indicator of voicing assimilation (see further section 3.3 below).

Figure 4 represents the mean duration of the voiced intervals of /p/ (C_1) and /s/ (C_2) across C_3 contexts. Perhaps the most striking aspect of this diagram is the marked increase in voicing before [+voice] stops relative to the remaining environments: the overall difference in C_1 + C_2 voicing between [+voice] and [–voice] C_3 contexts is 27 ms. This suggests that, contrary to the assertion by Brink (1975) and others, word-final /p/ + /s/ clusters are subject to some form of regressive voicing assimilation in Dutch.

A second noteworthy feature of Figure 4 is the seemingly disparate behaviour of the 3 baseline C_3 contexts. The amount of C_1 + C_2 voicing before /h/ and lexical vowels (phonetic [ʔ]) is virtually identical to the amount of voicing observed before [–voice] plosives. The mean duration of C_1 + C_2 voicing before word-initial /m/ however, falls almost exactly halfway between the amounts of voicing found before [–voice] (13 ms difference) and [+voice] plosives (14 ms difference).

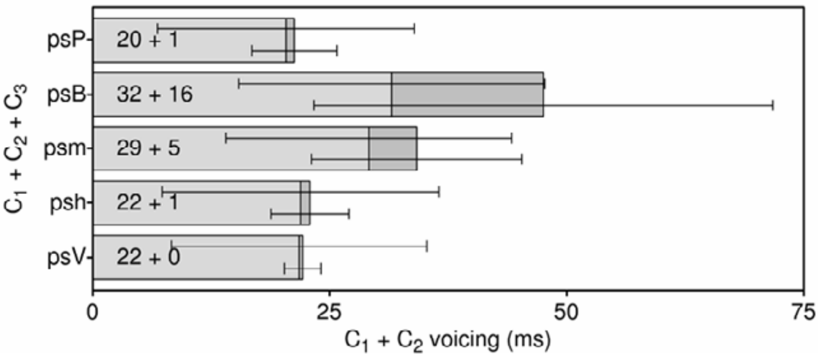

Figure 4: *Voicing of $C_1 + C_2$. Mean duration of the voiced intervals of /p/ (leftmost segments, light grey fill) and /s/ (rightmost segments, dark grey) across C_3 contexts. P represents /p, t/; B signifies /b, d/. Error bars represent the mean ± 1 standard deviation. All values in ms.*

Perhaps surprisingly, this implies that the word-final /ps/ sequences exhibit a three-way assimilatory pattern, with __/p, t/, __/h/, and __/V/ acting together as a 'voiceless' environment, __/m/ as an 'intermediate' environment, and __/b, d/ as a 'voiced' environment. On the assumption that __/m/ represents a true 'non-assimilation' environment, this in turn suggests that Dutch RVA is symmetric in regard to the feature [voice], with both [+voice] and [–voice] obstruents triggering regressive voicing assimilation.

A one-way ANOVA for C_3 laryngeal specification was performed on the C_1 + C_2 voicing data to test these impressionistic observations. The 3 baseline C_3 environments __/m/, __/h/, and __/V/ were included as three separate laryngeal specifications in addition to [–voice] (/p, t/) and [+voice] (/b, d/). This ANOVA shows a highly significant effect, $F(4,804) = 48.92$, $p < .001$, which indicates that the C_3 context indeed has some assimilatory effect on the voicing of preceding /ps/ clusters.

Next, Tukey and Scheffe post hoc tests were performed to establish which pairwise comparisons of the means displayed in figure 4 show statistically significant differences. The results of these post hoc tests, which are summarized in Table 2, indicate that all pairwise comparisons of the means for __/p, t/, __/b, d/, and __/m/ show statistically significant differences. This suggests that as far as C_1 + C_2 voicing is concerned these contexts should be regarded as distinct from each of the others, and thus that Dutch RVA is at least qualitatively [voice]-symmetric.

	/p, t/	/b, d/	/m/	/h/	/V/
/p, t/		*	*	n.s.	n.s.
/b, d/	*		*	*	*
/m/	*	*		*	*
/h/	n.s.	*	*		n.s.
/V/	n.s.	*	*	n.s.	

Table 2: *Results of Tukey and Scheffe post hoc tests on the ANOVAs for C_1 + C_2 voicing: *: significant difference (p < .05) according to both tests*

Note, moreover, that the differences between both __/h/ and __/V/ on the one hand, and __/b, d/ as well as __/m/ on the other hand are statistically significant according to both tests, which indicates that the effect of the (phonetic) glottals on the voicing of a preceding cluster is indeed likely to be distinct from that of the [+voice] plosives and /m/.

3.3 *C_1 + C_2 voicing 'classes'*

In his study of regressive voicing assimilation in Dutch two-way obstruent clusters, Slis (1986) employs a technique of quantifying RVA that is different from the method used in the previous section. Slis classifies all obstruents preceding a [+voice] plosive C_2 as 'unassimilated' if they have a *Voice Termination Time* (VTT) or 'voice tail' of < 50 ms and as 'showing regressive assimilation' if their VTT exceeds 50 ms. The cut-off point is based on the VTT of singleton intervocalic stops in Dutch as measured by Slis (1970), which indicates that there is a probability < .0025 that [–voice] stops have a VTT equal or greater to the mean of 25 ms + 2 standard deviations (10 ms) + 5 ms = 50 ms.

The method for quantifying RVA employed by Slis (1986) has two potential advantages, even if Dutch RVA turns out to be a gradient phonetic process that renders any description in terms of discrete categories completely arbitrary. First, it exposes the size of the effect of [±voice] on C_1 voicing duration relative to the inherent variance within a laryngeal category in an intuitively transparent way. Second, the relative magnitude of [±voice] effects vis-à-vis the noise caused by within-category variation may be used as a rough indicator of perceptual salience: O'Shaughnessy (1981) suggests that effects smaller than or equal to a single standard deviation from a baseline mean should be treated as below the threshold of perception.

There are several ways in which Slis's method can be applied to the C_1 + C_2 voicing data from the present experiment. Assuming that assimilation of C_1 + C_2 voicing is indeed [voice]-symmetric, a natural procedure is to define three 'voicing' classes using the *overall* mean C_1 + C_2 voicing duration of 31 ms and its standard deviation of 26 ms. This yields a *'voiceless'* category or 'band' with relatively short voiced intervals, a *'neutral voicing'* class centred around the overall mean, and a *'voiced'* category with relatively long voiced intervals.

Regardless of the precise settings of the boundary values delimiting the three categories, the picture of Dutch regressive voicing assimilation that emerges from this method does not seem to be substantially different from the one drawn in the

previous section. Figure 5 depicts the classification of /ps/ clusters if the neutral band is defined as the overall mean of 31 ms ± 1 standard deviation of 26 ms. There are very few ‘voiced’ clusters preceding [–voice] plosives, /h/, or /V/, whereas 30% of the cases before /b, d/ belong in this class, with the __/m/ context almost exactly halfway in between (15%). The frequencies of ‘devoiced’ clusters hint at the same natural classes of assimilation environments, with similar frequencies before /p,t/ and /h/ and /V/ (17, 18, and 15% respectively), and lower figures for /m/ (8%) and /b,d/ (3%).

It is interesting to compare the frequency of ‘voiced’ (‘assimilated’) final clusters found in this study to the numbers reported by Slis (1986). He reports that [+voice] stops trigger 86% ‘regressive assimilation’ in preceding singleton plosives across a word boundary and before stress, which is considerably higher than the proportion of ‘voiced’ cases before [+voice] plosives reported here. Note, however, that in the classification illustrated in figure 5 the cut-off point between the ‘neutral’ and ‘voiced’ bands is 57 ms of voicing as opposed to Slis’s 50 ms. If the cut-off point is lowered to 50 ms the proportion of ‘voiced’ cases before [+voice] plosives rises to 36%, which is identical to the frequency of ‘assimilated’ singleton fricatives found by Slis (in the relevant environment). This implies that, however real, the effect of RVA on plosive + fricative clusters are in some sense weaker than the effect on singleton plosives and therefore perhaps less audible. This may in turn account for the claims in the descriptive literature that regressive voicing assimilation does not apply to plosive + fricative clusters in Dutch.

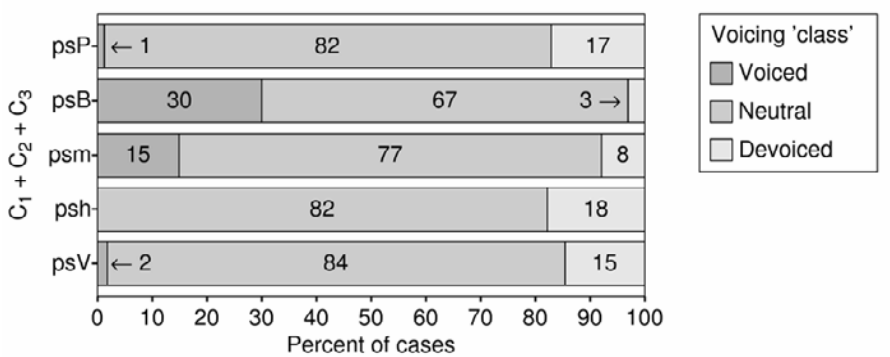

Figure 5: *Frequencies of ‘devoiced’, ‘neutral’, and ‘voiced’ /ps/ clusters before [–voice] stops, [+voice] stops, /m, h, V/ if the neutral category is defined as 31 ± 26 ms (the overall mean ±1 standard deviation). Numbers inside columns represent numbers of cases*

3.4 *C_1 + C_2 duration*

Segmental duration has often been regarded as a cue to [voice], at least in word-medial environments (Chen 1970, Raphael 1981, Luce & Charles-Luce 1985). There is some doubt regarding the robustness of stop occlusion duration as a correlate of [voice] in naturalistic speech (Crystal & House 1988), but there does seem to be a tendency for stop release bursts of [–voice] plosives and the frication

intervals of [–voice] fricatives (cf. Stevens et al. 1992) to be longer than those of their [+voice] counterparts.

In light of the cross-linguistically recurrent role of segmental duration in signalling [voice] contrast, it seems worthwhile to investigate whether it reflects the effects of RVA, although there is no a priori reason to expect it to do so. Generalising the way [voice] maps into segmental duration to the effects of RVA then, obstruents would be expected to shorten before [+voice] sounds and/or that they lengthen before [–voice] sounds when assimilation applies.

Figure 6 depicts the mean durations of C_1 and C_2 across C_3 environments. Note first of all, how the means for C_2 extend across a larger range (20 ms) than those for C_1 (8 ms). This suggests that any effects of RVA on obstruent duration are relatively 'local' in being restricted to sounds immediately adjacent to the trigger consonants. A second noteworthy feature of figure 6 is that before [–voice] plosives, [+voice] plosives and /m/ the mean durations for $C_1 + C_2$ overall and for C_2 separately are consistent with the assimilatory pattern of lengthening and shortening described above. Thus, there is a 22 ms positive difference in $C_1 + C_2$ duration between the [–voice] and [+voice] C_3 contexts, whilst /m/ (again) seems to act as an intermediate environment.

The duration of /ps/ before a lexical vowel, on the other hand, appears to be out of tune with this pattern. The voicing data reported above suggest that (the glottal stop preceding) a lexical vowel acts as a devoicing environment, which by the general inverse relationship between segmental length and voicing should have produced a relatively long $C_1 + C_2$ sequence. However, __/V/ is the 'shortest' context of all.

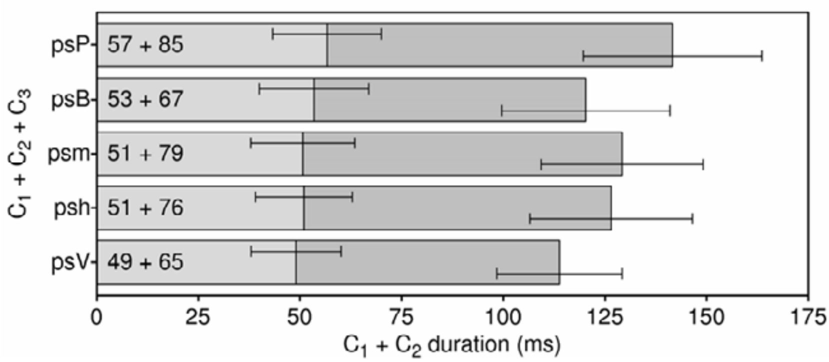

Figure 6: *Duration of $C_1 + C_2$. Mean segmental duration of /p/ (leftmost segments, light grey fill) and /s/ (rightmost segments, dark grey) across C_3 contexts.* P *represents /p, t/;* B *signifies /b, d/. Error bars represent the mean ± 1 standard deviation. All values in ms.*

A one-way ANOVA for C_3 *laryngeal specification* was performed on the $C_1 + C_2$ overall duration data with /m/ and /h, V/ again included as three separate laryngeal specifications in addition to [±voice]. This ANOVA yields a highly significant

effect, $F(4,804) = 25.77$, $p < .001$, which indicates that the status of C_3 does indeed have an effect on the duration of preceding obstruents.

Results of Tukey and Scheffe Post Hoc tests are summarized in Table 3. These indicate that there is a significant difference between the (relatively long) mean duration of /p + s/ before [–voice] plosives and $C_1 + C_2$ duration in all other contexts. Interestingly, the short duration of /p + s/ before /V/ emerges as significantly different from the means for /p, t/, /m/, and /h/ even though, as hinted above, a different pattern might be expected on the basis of the $C_1 + C_2$ voicing data and the usual inverse relationship between voicing and segmental duration more generally.

	/p, t/	/b, d/	/m/	/h/	/V/
/p, t/		*	*	*	*
/b, d/	*		*o*	n.s.	n.s.
/m/	*	*o*		n.s.	*
/h/	*	n.s.	n.s.		*
/V/	*	n.s.	*	*	

Table 3: *Results of Tukey and Scheffe post hoc tests on the ANOVA for $C_1 + C_2$ segmental duration. *: significant difference (p < .05) according to both tests; o: significant difference (p< .05) according to Tukey only; n.s.: difference not significant on either test*

3.5 V_1 *duration*

There is a crosslinguistic pattern for vowels (and sonorant consonants) to be shorter before (pre-stressed) [–voice] obstruents than before their [+voice] counterparts. Whilst widespread, the extent of this effect is language-specific (Chen 1970, Kluender et al. 1988). It has been documented for Dutch word-medial obstruents by Slis & Cohen (1969), who report a mean difference of 25 ms between vowels preceding word-medial [+voice] and [–voice] obstruents. Given its association with phonological voicing, both cross-linguistically and specifically for Dutch, preceding vowel duration should be regarded as a potential reflex of regressive voicing assimilation: the effects of lexical [voice] contrast on vowel length suggest that any such reflex would consist of vowel lengthening as a result of assimilation to [+voice] and/or vowel shortening triggered by assimilation to [–voice].

Figure 7 shows that differences in the mean duration of V_1 among the five contexts at hand are small (maximally 7 ms) and what differences emerge, are difficult to interpret in terms of assimilation to the [voice] value of C_3. A one-way ANOVA for C_3 *laryngeal specification* fails to yield any effect: $F(4,804) = 1.39$, not significant, which would seem to warrant the conclusion that voicing assimilation in two-way clusters has no effect on the length of vowels preceding such clusters.

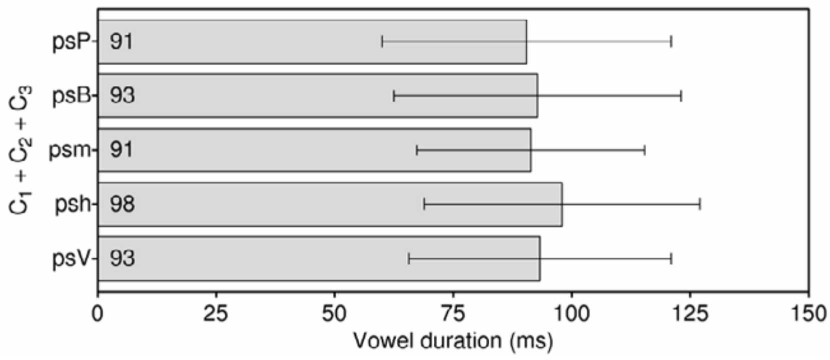

Figure 7: Mean duration (ms) of V_1 before /ps/ followed by /p, t/, /b, d/, /m/, /h/ and /V/. Error bars represent the mean + 1 standard deviation

3.6 *Low-frequency spectral features*

The ability of [–voice] and [+voice] obstruents to raise and depress respectively the F_0 (of the onset of) a following vowel is well-documented in the literature, and there is some evidence for similar effects of [voice] on F_1 trajectories (see Kingston & Diehl 1994 for an overview). In theory it is possible therefore, that voicing assimilation manifests itself in a lowering and/or raising of F_0 and F_1 during the offset of the vowel preceding an assimilated obstruent. In spite of the clear F_0 differences following C_3 consonants reported in section 3.1 there is little in the F_0 data evincing any form of regressive assimilation. The F_1 values of V_1 near vowel offset show only a small effect of C_3 that is (partially) consistent with regressive assimilation. Table 4 provides mean F_0 values at 10 ms before the onset of C_1 for the 2 female subjects, as well as mean F_1 values at 10 ms before the onset of C_1 pooled over all 4 subjects (recall that the carrier vowel is always /a:/). Note in this table how the F_0 means (and standard deviations) for vowels preceding clusters ending in /p, t/, /b, d/, /h/, and /V/ are virtually identical, whilst the mean for __/m/ is similar, too.[4]

Mean F_1 differences at 10 ms before the onset of C_1 are marginally greater, notably the 20 Hz difference between the [–voice] and [+voice] plosives. A one-way ANOVA for C_3 *laryngeal specification* on the F_1 values at 10 ms before the onset of C_1 (clusters ending in /h, V/ excluded) reveals a weakly significant effect, $F(2,578) = 4.23$, $p < .02$. This suggests that C_3 may indeed have a (weak) assimilatory effect on F_1.

C_3	♀ F_0 at C_1 - 10 ms	N	F_1 at C_1 - 10 ms	N
/p, t/	200 (40)	115	697 (93)	234
/b, d/	199 (39)	118	677 (87)	233
/m/	194 (31)	58	701 (77)	114
/h/	200 (35)	59	689 (81)	118
/V/	199 (33)	56	690 (95)	110

Table 4: Mean F_0 values (female speakers only) and F_1 values (both in Hz) of V_1 (/a:/) at 10 ms before the onset of C_1. Standard deviations in brackets

4. *Discussion*

The voicing data presented in sections 3.2 and 3.3 indicate that contrary to the assertions of some phonologists (Brink 1975, Cammenga & van Reenen 1980), regressive assimilation of voice can occur in Dutch stop + fricative + stop sequences. Regardless of the exact interpretation of the results, it would be difficult not to attribute differences in $C_1 + C_2$ voicing before /p, t/ and /b, d/ to some form of regressive voicing assimilation. As emphasized above in section 3.3, this conclusion remains the same whether RVA is quantified in terms of mean voicing differences or in terms of ‘voicing categories’ along the lines of Slis (1986). It remains a possibility, of course, that voicing assimilation is less prevalent, or otherwise less noticeable, in stop + fricative + stop sequences than in two-way clusters, and that this has ultimately led to categorical interpretations in the literature.

Whilst perhaps clarifying a somewhat under-researched aspect of regressive voicing assimilation in Dutch, the finding that stop + fricative + stop sequences do in fact exhibit assimilation does not in itself have major ramifications for phonological analyses of the process. Some models predict assimilation in words like /fiːts/ + /bɛl/ ‘bicycle bell’ (Booij 1981, Grijzenhout & Krämer 1998), others do not (e.g., Lombardi 1999), but nothing of great theoretical importance hinges on this.

A perhaps more problematic issue lies in the detail of the voicing data and also in the patterning of segmental duration. As mentioned before, the means of C_1 + C_2 voicing duration before [–voice] plosives, [+voice] plosives and /m/ suggest a tripartite pattern of assimilation, in which the nasal acts as an ‘intermediate’ context between the two obstruent classes. This pattern of voicing values can be interpreted as involving assimilation to both /b, d/ and /m/ with /p, t/ representing the neutral category; alternatively, it might be seen as ‘[voice]-symmetric’ assimilation to both /p, t/ and /b, d/, with the nasal representing the neutral category. However, as most recent phonological analyses treat [voice] in Dutch as monovalent (e.g., Lombardi 1994, 1999, Iverson & Salmons 1999), they are unable to derive tripartite patterns of assimilation.

Probably the easiest way out of this conundrum for proponents of these models is to maintain that [voice] is phonologically monovalent in Dutch and that any phonetic distinctions between __/p, t/ and __/m/ are merely the result of a ‘low-level phonetic process’. An analysis in this vein could run roughly as follows: se-

quences such as /ps + b/ are subject to assimilation to become [+voice] throughout in the phonology to become /bzb/. A natural phonetic interpretation of sequences of this type then assigns a relatively great amount of voicing to C_1 + C_2 (perhaps subject to some spontaneous devoicing later on). Clusters such as /ps + p/ and /ps + m/ are left untouched by the phonology and passed on to the phonetics, which assigns the initial stop and fricative identical amounts of voicing in both environments. Some minor readjustments then somehow produce a minor increase in C_1 + C_2 voicing before /m/ (or a decrease before /p/).

The remainder of this paper represents an attempt to show that the analysis sketched here probably provides the best fit with the data, albeit with one key modification such that any three-way cluster of C_1 (+ C_2) + C_3 is passed on to the phonetics as is, and that any C_3-induced changes in the voicing and duration of preceding obstruents stem from the *coarticulation of laryngeal gestures*. The essence of this analysis, which is largely similar to that of Ernestus (2000: section 7.4), is therefore that all of Dutch regressive voicing assimilation is a 'low-level phonetic process'.

The first step in this argument is to clarify some important terminology. I use *coarticulation* to refer to the observable results of articulatory strategies that manage the transitions between sounds produced in sequence. The results in question include phenomena such as the partial nasalization of vowels adjacent to nasal stops found in English and other languages (Cohn 1993); models such as *Articulatory Phonology* (Browman & Goldstein 1986, 1992) offer formal frameworks to capture the (hypothesized) articulatory strategies underpinning coarticulation effects.

There is evidence that the amount of coarticulation between two given sounds can be dependent on speech rate and prosody (Solé & Ohala 1991, De Jong et al. 1992, Byrd & Saltzman 1998), and that patterns of coarticulation are in part language-specific (e.g. Clumeck 1976), but the phenomenon itself is arguably a universal aspect of phonetic implementation (see Farnetani 1997). Consequently, invoking coarticulation as the mechanism underlying voicing assimilation in Dutch does not entail adding an otherwise superfluous module to the phonology-phonetics interface: it merely involves relocating the source of RVA to a different part of the interface.

There is a range of instrumental studies, in particular those by Löfqvist and his associates, that document aspects of laryngeal, or more specifically glottal, coarticulation in obstruent sequences (e.g., Yoshioka et al. 1982, Löfqvist & Yoshioka 1984, Löfqvist et al. 1989, Munhall & Löfqvist 1992; see Hoole 1999 for an overview). For example, Munhall & Löfqvist (1992) show how at slow speaking rates, the /s#t/ cluster in the phrase <Kiss Ted> tends to be articulated with two separate abduction gestures (opening and closing movements of the glottis) which gradually merge as speaking rate increases, initially producing a single gesture with two abduction peaks, and producing one single-peaked gesture at the highest rates. An earlier study (Yoshioka et al. 1982) presents (more limited) data showing the merging of abduction gestures in Dutch obstruent clusters. From the present perspective it is perhaps unfortunate that most if not all of the work on glottal coar-

ticulation in obstruent clusters investigates sequences of [–voice] sounds rather than mixed [voice] clusters, but it nevertheless establishes that (aspects of) laryngeal articulation are subject to considerable coarticulation effects, in much the same way as other areas of segment production.

In the absence of articulatory data, the common practice of distinguishing between phonetic and phonological processes on the basis of their systematically gradient or discrete mode of application provides a relatively useful test to classify assimilation rules: their capacity for systematically neutralizing (lexical) phonological distinctions among the sounds they target. If a rule (all but) erases phonetic distinctions between, say, underlyingly [+voice] and [–voice] obstruents whenever it applies, it seems safe to infer that it represents a phonological process. If, on the other hand, the application of a rule tends to leave a phonetic residue of the underlying phonological distinction, it may represent a coarticulation process. Unfortunately, this test is unavailable for the case at hand as word-final [voice] contrast is (near-)neutralized on independent grounds in Dutch.

Nevertheless, the data reported in this paper are largely consistent with a view of RVA as arising from anticipatory laryngeal coarticulation. Since this view yields a uniform account of the observed behaviour of /ps/ on the basis of an independently motivated mechanism, I think it should be preferred over a hybrid account which attributes voicing assimilation in 4 out of 5 environments to coarticulation (or some other phonetic process) but which treats voicing and duration effects in the remaining environment as the result of a phonological rule (which must be postulated separately). The following sections outline how, under certain assumptions, the behaviour of /ps/ clusters in each of the 5 environments is expected on grounds of anticipatory coarticulation.

4.1 *[–voice] and final obstruents*

Most recent models of (West-Germanic) laryngeal phonology treat the single series of word-final obstruents found in Dutch as phonologically identical to the contrastively voiceless obstruents found initially and medially. According to e.g., Lombardi (1994, 1999) and Iverson & Salmons (1999) this single class of contrastively voiceless and neutralized (voiceless) stops represents the laryngeally unmarked category. By contrast, Ernestus (2000) claims that contrastively voiceless and neutralized obstruents represent two distinct phonological and phonetic classes: the former phonologically marked and actively devoiced phonetically; the latter phonologically unmarked and phonetically underspecified for voicing. Both classes are distinct from phonologically marked [+voice] obstruents, which are actively voiced at the phonetic level (see also Hsu 1996 on Taiwanese, and Steriade 1997).

Ernestus's principal argument for this three-way classification of Dutch obstruents is that the phonetic voicing of final obstruents is much more dependent on phonetic context and other (extralinguistic) factors than the voicing of contrastively voiceless or voiced obstruents. In other words, with respect to phonetic voicing the neutralized final obstruents of Dutch behave much like the [+voice] plosives of English, which some have long regarded as passively (de)voiced (cf.

Harms 1973). For example, unlike their contrastively voiceless counterparts, final obstruents may be (audibly) voiced before sonorant consonants.

Now the claim that Dutch final obstruents are phonetically underspecified for voicing (and presumably other phonetic cues to [voice]) and therefore subject to passive voicing and devoicing hardly contradicts the approach of Lombardi (1994, 1999), Iverson & Salmons (1999), and similar models. In fact, variants of this approach that tie phonological unmarkedness directly to phonetic underspecification (Harris 1994) predict precisely that this is the case. It is rather the claim that the contrastively voiceless obstruents are actively devoiced that is potentially problematic for these models.

Fortunately, there is some instrumental evidence to support this idea. Löfqvist et al. (1989) conducted an electromyographic (EMG) study of cricothyroid (CT) activity during the production of Dutch and English obstruents. They report increased levels of CT activity relative to the surrounding vowels during both American English [–voice] obstruents, which are quite commonly regarded as actively devoiced, and Dutch voiceless obstruents. Contraction of the cricothyroid muscle results in a stiffening of the vocal folds, and Löfqvist et al. (1989) argue that this can be seen as a devoicing strategy since stiff(er) vocal folds vibrate less easily.

Moreover, they claim that the timing of the peak in CT activity is such that the resulting increase in vocal fold tension peaks around the point of consonantal release. This is consistent with the idea that it is CT activity that is mainly responsible for the raised F_0 after the offset of [–voice] obstruents. Löfqvist et al. (1989) mention two further observations in support of the hypothesized link between CT activity and F_0 raising. First, there is a statistically significant correlation between the amount of CT activity during the production of a [–voice] obstruent and the F_0 of the first period of the following vowel; and second, the absence of a significant F_0 difference at the offset of the lexical affricates /tʃ/ and /dʒ/ of one of their English speakers coincides with the absence of raised CT activity during the [–voice] affricate.

Note that Löfqvist et al. (1989) are keen to point out that any differences in CT activity between [+voice] and [–voice] obstruents are due to increased activity in the latter rather than decreased activity in the former, which exhibit no substantial deviation from levels of CT activity in the surrounding vowels. Assuming that there indeed is a link between CT activity in obstruent production and F_0 levels in following vowels, this suggests that F_0 differences at the offsets of (Dutch and English) [+voice] and [–voice] obstruents are solely due to F_0 raising after the latter. This tallies neatly with the observation in 3.1 that F_0 is roughly the same at the offset of /b, d/ and /m/ (cf. Figure 3).

The CT study of Löfqvist et al. (1989) can hardly be treated as decisive given the fact that it involved only one Dutch-speaking subject, and also in light of an earlier study by Collier et al. (1979), which fails to find increased CT activity during the production of Dutch [–voice] obstruents. However, some additional support for the idea that these obstruents are actively devoiced may be gleaned from the paper by Yoshioka et al. (1982) already mentioned above. EMG data on poste-

rior cricoarytenoid (PCA) activity during the production of Dutch [– voice] obstruents shows small peaks associated with word-initial /p/, whilst the corresponding glottal transillumination data shows a small abduction gesture (no data are provided on /t/ or /k/). Since PCA contraction contributes to vocal fold abduction, it is easily construed as a devoicing strategy, and consequently the presence of increased PCA activity during the production of [–voice] stops may well be a sign of active devoicing.[5]

Interestingly, Yoshioka et al. (1982:31) comment on the “negligible size” of any increase in PCA activity and glottal abduction during the production of word-final /p/. They attribute this observation to “the glottalization of a stop sound in this position”, but unlike (several dialects of) English, Dutch does not normally glottalize final stops. The virtual absence of PCA activity and glottal abduction during word-final /p/ is therefore perhaps better attributed to phonetic underspecification of [voice], or alternatively to phonetic reduction of the already small abduction gesture associated with word-initial /p/.

Given that neutralized final and contrastively voiceless obstruents belong to two distinct phonetic categories, it is unsurprising that the latter trigger some degree of devoicing in the former relative to sounds that are not actively devoiced, such as [m]. The active devoicing measures associated with [–voice] word-initial obstruents is likely to carry over to some extent into preceding voice-underspecified obstruents, and it does not seem implausible that this clips the voicing of these underspecified sounds somewhat relative to passively voiced environments.[6]

Moreover, to the extent that anticipatory coarticulation of actively devoiced word-initial plosives has an effect on the frication interval of preceding [voice]-underspecified word-final fricatives, this effect is likely to positive. The generation of sustained turbulence noise at an oral constriction is critically dependent on high transglottal airflow, and this motivates the large glottal abduction gestures typically associated with voiceless fricatives (Stevens et al. 1992, Stevens 1998). Consequently, coarticulating a [voice]-underspecified fricative with a segment that is itself associated with a glottal abduction gesture (albeit a small one) may well increase the duration of the interval during which transglottal airflow is above the critical threshold for noise generation.

In sum then, assuming that word-final neutralized obstruents are underspecified for [voice], coarticulation with a following actively devoiced obstruent is likely to result in a decreased amount of voicing, and in the case of fricatives, a relative increase in duration.

4.2 *[+voice] obstruents*

Aerodynamic models of the vocal tract indicate that a number of supplementary articulatory strategies are required in addition to vocal fold adduction to produce phonetically voiced stops post-pausally and after another obstruent (Ohala 1983, Westbury & Keating 1986, Stevens 1998). A number of the (possible) strategies involved (larynx lowering, tongue root advancement, raising of the soft palate, relaxing the tissue lining the vocal tract walls) are aimed at maintaining a transglottal pressure difference that is sufficient for voicing by expanding the cav-

ity behind the oral occlusion; others (decreasing vocal fold tension) aim to lower the transglottal pressure threshold below which voicing is impossible (Ladefoged 1973, Stevens 1998).

I am not aware of any instrumental studies documenting the deployment of these active voicing measures in the production of Dutch [+voice] stops, but it seems safe to assume that at least some of them are deployed by speakers of (southern and western varieties of) Dutch.

As a result, anticipatory coarticulation of actively voiced plosives such as Dutch /b, d/ is likely to improve the conditions for voicing during preceding [voice] underspecified obstruents, and therefore to increase the amount of voicing relative to other contexts. Whether the broad magnitude of the voicing effect observed in sections 3.2 and 3.3 follows from the active voicing measures deployed by speakers of Dutch is a matter that can only be resolved on the basis of articulatory data and vocal tract modelling, but it seems that in qualitative terms the effect is as expected on the basis of laryngeal coarticulation.

In addition, a coarticulation-driven account predicts the relatively short duration of the C_2 fricative before [+voice] plosives, which accounts for practically all of the reduction in C_1 + C_2 overall duration in this environment. Actively voiced stops are minimally accompanied by a glottal adduction gesture, and any anticipatory coarticulation of this gesture would lead to some amount of reduction in the temporal extent and peak glottal width of the abduction gesture associated with a preceding fricative. This would in turn reduce the window during which transglottal airflow is sufficient for the production of turbulence noise at the alveolar ridge, and consequently reduce the duration of the frication interval of /s/.

In other words, it is unnecessary to postulate a phonological rule spreading [+voice] to derive an increase in the amount of C_1 + C_2 voicing and a decrease in (C_1 +) C_2 duration before b, d, even though it remains to be seen if the magnitude of the voicing effect observed above can be derived from coarticulation alone.

4.3 */m/*

The Dutch bilabial nasal is generally produced fully voiced, but in the absence of contrastive voicing in the Dutch nasal inventory, it seems perfectly reasonable to assume that this is the result of spontaneous voicing, and thus that /m/ is not accompanied by any local laryngeal gestures. Consequently, there is nothing at the laryngeal level for anticipatory coarticulation to spread into the preceding obstruents, and /ps/ +/m/ clusters are subject to spontaneous voicing (during the early stages of the obstruent clusters and during the nasal) and spontaneous devoicing (during the remainder of the obstruent cluster) throughout.

This means that a coarticulation-based account predicts that C_1 + C_2 voicing and duration values for /ps/ + /m/ sequences are roughly intermediate between those for /ps/ + /b, d/ sequences, in which the obstruent cluster is likely to acquire some amount of active voicing, and those for /ps/ + /p, t/ clusters, in which C_1 + C_2 is likely to acquire some amount of active devoicing.

4.4 */h/*

The Dutch glottal fricative has been represented as phonologically [–voice] by some phonologists (Trommelen & Zonneveld 1979) but as [+voice] by others (Booij 1981), and has been described as phonetically voiced [ɦ] (e.g., Gussenhoven 1999). However, the key to understanding Dutch /h/ and its possible coarticulatory effects on a preceding /ps/ sequence is not to read too much into these labels and/or to treat it on a par with oral consonants, but to take a closer look at its phonetic realization.

According to Rietveld & Loman (1985), quoting Slis & Damsté (1967), transillumination evidence suggests that intervocalic /h/ is characterized by a glottal abduction gesture comparable to that of (contrastively) “voiceless intervocalic fricatives and plosives”, but they point out that vocal fold vibration is possible during (much of) this abduction gesture due to relatively favourable aerodynamic conditions (i.e., the lack of increasing intra-oral pressure). As would perhaps be expected on the basis of this information, electroglottographic and acoustic data collected by Rietveld & Loman (1985) indicates that the voicing of Dutch /h/ is subject to a great deal of contextual variability. For example, they report that utterance-initially and after voiceless /s/ the glottal fricative is realized with an initial voiceless interval with a mean duration of around 40 ms. After /n/ or a vowel, on the other hand, this voiceless interval is nearly always absent.

Data from the present experiment are in broad agreement with these findings. In C_3 position /h/ is realized with an initial interval of voiceless aspiration in 94% of cases; the mean duration of this interval is 34 ms. Interestingly, in the tokens produced by the two female subjects the mean F_0 at 10 ms after the onset of voicing is 204 Hz, and this rises to 221 Hz at 50 ms. This is much lower than the values found after the offset of [–voice] /p, t/ and lower even than the values found for /m/ and /b, d/ (see figure 3; similarly low values were obtained for the male subjects). Even if the offset of /h/ could not be reliably segmented, it is safe to assume that measuring F_0 at 10 ms after the onset of voicing in /h/ is hardly equivalent to measuring F_0 10 ms after the offset of an oral consonant and not too much weight should therefore be attached to the exact F_0 value. Nevertheless, in terms of its effects on F_0, /h/ should probably be grouped with /b, d/ and /m/ rather than with the [–voice] plosives, and extrapolating to underlying CT activity this implies that /h/ should not be regarded as actively devoiced. Since there are no indications (or aerodynamic grounds on which it is plausible) that /h/ is actively voiced either, the most straightforward analysis of this sound treats it as spontaneously voiced.

The key to its effect on the voicing of a preceding obstruent cluster, then, should be sought not in active devoicing measures but simply in the anticipatory coarticulation of its abduction gesture. The glottal fricative itself may be partially or wholly voiced in spite of it, but when an oral constriction is superimposed on glottal abduction in the absence of any articulatory strategies promoting voicing (as in voiced fricatives) the outcome is devoicing. Consequently, anticipatory coarticulation of the abduction gesture associated with /h/ is likely to result in a

decrease in voicing in a preceding [voice]-underspecified obstruent cluster, even if the trigger is not itself realized as fully voiceless.

A (potential) problem with this account is that the logic of section 4.1 would seem to predict a longer duration for the /s/ immediately preceding the /h/ than the value obtained from the experiment, which is 9 ms shorter than the duration of /s/ before /p, t/ rather than in the same range, or longer. I currently have no solution to this problem.

4.5 */V/*

The behaviour of /ps/ before lexical vowel is probably the clearest clue that anticipatory laryngeal coarticulation plays an important role in shaping the duration and voicing of /ps/ clusters across the contexts studied here.

As mentioned above, lexical vowels were generally preceded by a glottal stop. The glottal compression gesture involved in the production of a glottal stop is a well-known inhibitor of vocal fold vibration. It seems likely therefore that the coarticulation of this gesture has a negative effect on the voicing of preceding obstruents. At the same time, coarticulation of glottal compression is likely to cause a shortening of /s/ relative to other environments by virtue of the same mechanism that shortens the fricative before [+voice] stops: reduction of the size and temporal extent of the glottal abduction gesture that is critical to the production of turbulence noise.

Thus, a coarticulation-based account provides a straightforward explanation of the cooccurrence of two effects (devoicing and shortening) that might seem puzzling from a more phonological approach to the realization of [voice] contrast.

5. *Conclusions*

This paper has attempted to defend two principal claims. The first simply holds that regressive voicing assimilation occurs in Dutch fricative + stop + fricative sequences. The second claim is that regressive voicing assimilation, at least in these clusters, reflects the effects of anticipatory coarticulation rather than the effects of a phonological rule and a set of separate, ‘low level’, phonetic processes.

The first claim receives solid support from the results of the experiment reported here. It is probably worthwhile to stress again that regardless of observations concerning the remaining 3 contexts, the clear difference in $C_1 + C_2$ voicing between [+voice] and [–voice] environments evinces regressive assimilation in production, even by the criteria applied by Slis 1986. This finding does not in itself have far-reaching ramifications for phonological theory, but it roundly contradicts the claims of Brink (1975) and Cammenga & van Reenen (1980) with regard to assimilation in three-way obstruent clusters, to the extent at least that these claims pertain to production rather than perception.

The second claim is largely consistent with the detail of the $C_1 + C_2$ voicing and duration data and, given that anticipatory coarticulation is available anyhow as part of the linguistic phonetics as a source of ‘low-level’ phonetic processes, it entails a more parsimonious model of Dutch RVA than one that employs an additional rule of RVA in the phonology. In addition, the phonetic manifestation of

Dutch RVA in the clusters investigated here exhibits similarities with assimilatory patterns in English obstruent sequences investigated by Jansen (2004, in press). The latter arguably represent coarticulatory processes because they are non-neutralizing and in particular because they do not affect vowel length distinctions between underlyingly [+voice] and [–voice] obstruents. Nevertheless, given the absence of key articulatory data, this second claim must remain far more speculative, and no doubt contentious, too.

Note, finally, that even if the analysis proposed here proves correct for voicing assimilation in three-way clusters, this does not entail that it extends to RVA in other contexts. Claims to this effect can only be substantiated on the basis of additional phonetic research, and I have little doubt that such research would bring to light further complications of textbook views of voicing assimilation in Dutch and elsewhere.

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Notes

1. The Dutch glottal fricative has been treated as phonologically [–voice] (Trommelen & Zonneveld 1979) but, as a reviewer points out, is sometimes regarded as voiced [ɦ] phonetically, at least in some contexts (cf. Gussenhoven 1999). The voiced/voiceless status of the Dutch glottal fricative is discussed in some detail in section 4 below; meanwhile I have opted to use /h/ in broad, 'phonemic', transcriptions.

2. Subjects were tested on an additional set of stimuli during the experiment. The target consonant sequences in this set combined an initial /k/ (orthographic <k>) and medial /s/ with a /p, t, b, d/ in C_3 position. Data from this part of the experiment is excluded from the discussion below as the behaviour of /ks/ clusters was not found to be significantly different from that of the corresponding /ps/ sequences.

3. Strictly speaking it is not clear whether these morphemes are [–voice] /s/ or unspecified for [voice] but for typographical reasons I will represent them as /s/.

4. The corresponding values for the 2 male subjects exhibit a similar pattern: /p, t/ = 162 Hz (25); /b, d/ = 163 Hz (26); /m/ = 168 Hz (27); /h/ = 163 Hz (27); /V/ = 163 Hz (28).

5. The [–voice] fricative /s/ shows much higher levels of PCA activity, but in light of the glottal abduction required for the production of (sibilant) fricatives (see below), this is not necessarily a sign of active devoicing.

6. Note, incidentally, that it is not uncommon for short lag VOT [–voice] plosives of the type found in Dutch to trigger RVA in preceding [+voice] obstruents, as for example in French (Dell 1995), Yiddish (Katz 1987), and Hungarian (Kenesei et al. 1998, Siptár & Törkenczy 2000; see Toft & Jansen 2003, Jansen 2004 for preliminary phonetic data). This observation has always been somewhat of an embarrassment to monovalent models of [voice] contrast (cf. Wetzels & Mascaró

2001), and may be an indication that [–voice] short lag VOT stops are actively devoiced more generally.

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Intraparadigmatic Effects on the Perception of Voice

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In Dutch, all morpheme-final obstruents are voiceless in word-final position. As a consequence, the distinction between obstruents that are voiced before vowel-initial suffixes and those that are always voiceless is neutralized. This study adds to the existing evidence that the neutralization is incomplete: neutralized, alternating plosives tend to have shorter bursts than non-alternating plosives. Furthermore, in a rating study, listeners scored the alternating plosives as more voiced than the non-alternating plosives, showing sensitivity to the subtle subphonemic cues in the acoustic signal. Importantly, the participants who were presented with the complete words, instead of just the final rhymes, scored the alternating plosives as even more voiced. This shows that listeners' perception of voice is affected by their knowledge of the obstruent's realization in the word's morphological paradigm. Apparently, subphonemic paradigmatic levelling is a characteristic of both production and perception. We explain the effects within an analogy-based approach.

1. *Introduction*

In many languages, morpheme-final obstruents alternate between voiced and voiceless, depending on their position in the word. Such obstruents are generally voiced before vowel-initial suffixes, and voiceless elsewhere (unless they are subject to regressive voice assimilation). To give an example, the final obstruent of the Dutch morpheme *mand* 'basket' is voiced in the plural [mɑndən] *manden* and voiceless in the singular [mɑnt] *mand* (in this article we only give broad transcriptions). A word's morphological paradigm, which we define as consisting of all other words containing the word's stem, may thus show alternation in the voice specification of the stem-final obstruent.

This alternation of voice within morphological paradigms raises the question of whether the voiced stem-final obstruents affect the acoustic characteristics and interpretation of their intraparadigmatic voiceless counterparts. In other words, does the presence of [mɑndən] *manden* in the morphological paradigm of *mand* affect the production and interpretation of the [t] of [mɑnt] *mand*?

In generative grammar, the alternation between voiced and voiceless obstruents is traditionally accounted for by means of underlying forms. A morpheme-final obstruent that is voiced before vowel-initial suffixes is also voiced in the underlying form. Thus, the underlying form of [mɑnt] is /mɑnd/ because of the

voiced [d] in the plural [mɑndən]. Obstruents that are voiced in the underlying form are devoiced in syllable-final position by a rule or constraint of Final Devoicing (e.g., Booij 1995), which turns the /d/ of the singular /mɑnd/ into [t]. Within generative grammar, the question of the effect of voice alternation on production and perception can thus be considered as a question of the effect of the underlying voice specification.

In this paper, we will not refer to the notion of underlying form. Recent studies have shown that the mental lexicon contains form representations for a great many words, including inflected forms (e.g., Jackendoff 1975, Baayen, Dijkstra & Schreuder 1997, Alegre & Gordon 1999, Baayen, McQueen, Dijkstra & Schreuder 2003). Thus, it contains the singular [mɑnt] as well as the plural [mɑndən]. Given the storage of plurals, the realization of the stem-final obstruent in the plural need not be stored as a diacritic on the stem. It is already stored in the representation of the plural itself. We tentatively assume that all forms that are stored in the mental lexicon are surface representations, which reflect the actual realization of the forms, and that the lexicon does not contain abstract underlying forms. We refer to stem-final obstruents that surface as voiced in some forms of their paradigm as "alternating obstruents" (instead of "underlyingly voiced" obstruents), and we regard possible effects of voice alternation as intraparadigmatic effects, which the different forms of the same morphological paradigm may exert upon each other.

Previous studies have documented an effect of intraparadigmatic voice alternation in production for several languages, including Dutch, German, Polish, and Catalan (e.g., Dinnsen & Charles-Luce 1984, Port & O'Dell 1985, Slowiaczek & Dinnsen 1985, Port & Crawford 1989, Charles-Luce 1993, Warner, Jongman, Sereno & Kemps 2004, Ernestus & Baayen 2006). Although all word-final obstruents are generally voiceless in these languages, the alternating obstruents tend to have more acoustic characteristics of voiced obstruents than non-alternating obstruents, which are always voiceless. These alternating obstruents tend to be shorter, to be realized with vocal fold vibration during a longer period, and to be preceded by longer vowels. Thus, the [t] of a word such as [mɑnt] *mand* 'basket' tends to have more acoustic characteristics of voiced obstruents than the [t] of a word such as [krɑnt] *krant* 'newspaper', which has the plural [krɑntən] *kranten*. Hence, the neutralization at word-final position between alternating and non-alternating obstruents is incomplete. In what follows, we will refer to voiceless obstruents that possess some acoustic characteristics of genuine voiced obstruents, such as a relatively short duration or a relatively long preceding vowel, as weakly voiced.

For Dutch, the realization of alternating and non-alternating obstruents in existing words has been investigated by Warner et al. (2004). They carried out a production experiment with 15 native speakers of Dutch, and found a significant difference in vowel duration of 3.5 ms. Ernestus & Baayen (2006) carried out a production experiment with pseudowords. The alternating/non-alternating character of final plosives was indicated by their spelling: in Dutch, alternating plosives are represented by graphemes for voiced phonemes ([b] or [d]) in all posi-

tions in the word, while non-alternating plosives are represented by graphemes for voiceless phonemes ([p] or [t]). Ernestus and Baayen found a statistically significant difference between the alternating and non-alternating final plosives with respect to the duration of their release noise (their burst and the following period of aspiration). The release noises of plosives represented as voiceless were on average 23 ms longer than the release noises of plosives represented as voiced.

Several authors, however, argue that incomplete neutralization is not a characteristic of spontaneous speech, but would be induced by spelling, especially when speakers are asked to read aloud minimal word pairs such as *Rat–Rad* (e.g., Fourakis & Iverson 1984, Warner, Good, Jongman & Sereno 2006). Thus, Fourakis & Iverson (1984) reported a series of experiments in which speakers showed incomplete neutralization when reading aloud minimal word pairs, but failed to do so when they repeated infinitives and produced the corresponding past-tense forms and past participles. In contrast, Ernestus & Baayen (2006) revealed that speakers may also show incomplete neutralization when they read aloud lists of pseudowords without detecting the minimal word pairs and without being aware of the purpose of the experiment. Moreover, Dinnsen & Charles-Luce (1984) showed that incomplete neutralization is also present in Catalan minimal word pairs that do not reflect the difference between alternating and non-alternating obstruents in their spelling.

What is important for the present study is not so much whether speakers produce incomplete neutralization also in spontaneous conversations, but that listeners are sensitive to the fine acoustic differences induced by incomplete neutralization. Although the acoustic differences between alternating and non-alternating obstruents are generally small, listeners are able to take advantage of these subtle differences. They assign the correct spelling at significantly above chance level to the members of minimal word pairs that differ from each other only in the alternating/non-alternating character of the final obstruent (e.g., Port & O'Dell 1985, Port & Crawford 1989, Warner et al. 2004). For instance, when Dutch listeners hear [rat], they assign, at just above chance level, the intended meaning *raad* 'advice' with the plural [radən], or *raat* 'comb' with the plural [ratən]. They opt slightly more often for *raad* when the final obstruent is weakly voiced, and for *raat* when the obstruent is completely voiceless.

Additional evidence for listeners' sensitivity to incomplete neutralization comes from listeners' choices of allomorphs for pseudowords. In Dutch, the choice between the past tense allomorphs *–de* [də] and *–te* [tə] depends on the alternating/non-alternating character of the stem-final segment. If the segment is always realized as voiceless, the appropriate allomorph is *–te*, otherwise it is *–de* (see also Zonneveld, this volume). Ernestus & Baayen (2003) showed that when speakers do not know how the final obstruent is realized in morphologically related words, that is, when they have no information about whether it is an alternating obstruent, they tend to base their choice between *–te* and *–de* on the word's phonological similarity neighbourhood. If most words ending in the same type of rime take –te, speakers tend to choose *–te*, and if most words take *–de*, the majority of speakers choose *–de*. Ernestus & Baayen (2006) found that listeners also

choose *–de* more often when the final obstruent is realized with weak voicing. This shows that listeners base their choice in addition on the detailed acoustic characteristics of the words. They are sensitive to incomplete neutralization even when this is not a requirement for the task that they are performing.

Lahiri, Jongman & Sereno (1990) also studied intraparadigmatic effects in the processing of voice. They carried out an experiment in which listeners of Dutch heard a verbal stem followed by the clitic pronoun *d'r* 'her' (the prime), and then performed auditory lexical decision on the same verbal stem in isolation (the target), realized with a voiceless final obstruent. The consonant cluster in the prime, consisting of the final obstruent of the verbal stem and the initial consonant of the clitic pronoun, was realized as voiceless (e.g., [kistər] *kies d'r* 'choose her'), or as voiced ([kizdər]). Both realizations are well-formed in Dutch (e.g., Zonneveld 1983). Listeners appeared to respond faster to target words ending in alternating obstruents when these obstruents were voiced in the prime, and to target words ending in non-alternating obstruents when these obstruents were voiceless in the prime. Unfortunately, Lahiri et al. do not report details on the acoustic characteristics of the target words, and it is therefore not clear to which extent the participants' behaviour might have been affected by incomplete neutralization. In addition, the study reports no statistics, and it is therefore not clear for which obstruents the observed differences are actually statistically significant, and even whether any of the reported differences reach significance.

In another study, Jongman, Sereno, Raaijmakers & Lahiri (1992) reported an experiment suggesting that the interpretation of a vowel as phonologically long or short depends on the alternating/non-alternating character of the following voiceless final obstruent. Listeners seem to attribute part of the length of a vowel to weak voicing if the following obstruent is alternating. The study does not report any statistics, but it does report for each participant the crossover boundaries (in ms) for each of the three studied word pairs, which differ in the alternating/non-alternating character of the final obstruents. Our analysis of these data show, unfortunately, that the differences between the word pairs fail to reach significance at the five-percent level (effect of word pair in an analysis of variance: $F(2, 42) = 2.70$; $p = 0.08$), so that it is uncertain what conclusions might be drawn from this study.

Summing up, previous studies have shown that alternating obstruents tend to be weakly voiced, at least in careful speech, and that listeners are sensitive to the subtle cues for weak voicing in the acoustic signal. In other words, the intraparadigmatic realizations of an obstruent affect its production in word-final position by inducing incomplete neutralization, and they affect word comprehension by the mediation of incomplete neutralization in the acoustic signal.

The present study addresses the question of whether voice alternation might affect speech perception over and above mediation by incomplete neutralization in the acoustic signal. That is, does the listeners' knowledge about a word's morphological paradigm codetermine their percept of this word? Thus, does the lexical information about the plurals of [mɑnt] and [krɑnt] ([mɑndən] and [krɑntən]) cause listeners to perceive the [t] of [mɑnt] as more voiced than the [t] of [krɑnt]?

We report a transcription experiment in which listeners, who are not phonetically trained, rated word-final obstruents on a five point scale as voiceless or voiced. Several authors (e.g., Vieregge 1987, Cucchiarini 1993) have argued that the phonetic transcription of speech sounds may be affected by their orthographic representations, the phonotactics of the language, and semantics. In addition, Kemps, Ernestus, Schreuder & Baayen (2005) have shown that the transcription of reduced word forms is affected by their unreduced counterparts. Listeners report the presence of [l] in words ending in the suffix *–lijk* [-lək], even when this suffix is reduced to [k]. In the present study, we investigated whether phonetic transcriptions made by naive participants might also be affected by lexical information about the segments' realizations in the word's morphological paradigm. Such information is of no use in a transcription task, where listeners have to base their judgments exclusively on the acoustic signal. In fact, intraparadigmatic effects, if present, would give rise to less accurate phonetic transcriptions. Hence, if we find such intraparadigmatic effects for naive participants, these effects must be automatic, that is, not available to participants for conscious, strategic control, and therefore a characteristic of everyday speech perception.

We opted for a rating task, instead of a traditional transcription task in which listeners represent sounds by IPA-symbols, because a rating may reveal more subtle differences in the listeners' percept of the voicing of alternating and non-alternating obstruents. We presented one group of listeners with full words, and another group with the final rimes of the same words. Since incomplete neutralization may be present in the acoustic signal, we may expect a difference between the ratings for the alternating and non-alternating obstruents by all listeners. Crucially, the listeners hearing the words could identify all words presented, and their judgments could therefore also be affected by lexical information about the intraparadigmatic realizations of the final obstruents. In contrast, the listeners hearing the rimes could identify the presented words only in a smaller number of cases, and a lexical effect on their judgments, if present, would necessarily be smaller. Hence, if intraparadigmatic realizations affect the perception of voice, we may expect a difference between the two groups of listeners, such that listeners hearing full words rate alternating obstruents as more voiced.

We expect intraparadigmatic effects to be smaller for fricatives than for plosives, since in Dutch the voiced-voiceless opposition is weaker for fricatives. Many speakers of Dutch tend to realize /z/ as [s], and even more speakers tend to realize /v/ as [f] in all positions in the word (e.g., Collins & Mees 1981:159; Gussenhoven & Bremmer 1983:57). Furthermore, the voicing of fricatives is highly predictable after vowels, as within words voiced fricatives are nearly always preceded by long vowels, and voiceless fricatives by short vowels. Finally, the difference between alternating and non-alternating obstruents is represented in orthography for plosives only. Final plosives that alternate in voice are always represented as voiced, and non-alternating plosives are always represented as voiceless. To give an example, the orthographic representations *mand* and *krant*, which are both realized with [t], show that the former morpheme is realized with [d] in the plural, while the latter morpheme is always realized with [t]. Fricatives, in

contrast, are invariably represented as voiceless at the end of syllables. Their orthographic representations reveal nothing of their alternating/non-alternating character. Thus both [bɑs] 'bass' and [bas] 'boss' are orthographically transcribed with *s* (*bas*, *baas*), although the plural of [bas] is [bazən] *bazen* with a voiced [z]. In other words, whereas orthography reinforces the voiced-voiceless opposition for plosives, it does not do so for fricatives.

The participants rated the voicing of the final obstruents on a five point scale. In order to ensure that this five point scale would correspond with the full range of completely voiceless to completely voiced, we included realizations with completely voiced final obstruents in the experiment, which are unnatural in Dutch. Thus, the experiment also included realizations such as [pard] (from [part] 'horse') and [kaz] (from [kas] 'cheese').

The materials and the recording procedure are described in section 2. This section also reports acoustic analyses that we carried out in order to ascertain whether our speaker had realized alternating obstruents as weakly voiced, and in order to document the acoustic characteristics of the voiced final obstruents. In section 3, we present the actual rating experiment. Section 4 summarizes the findings and presents our conclusions. Moreover, it discusses how to incorporate our findings in the grammar of Dutch.

2. *Materials*

We selected 94 monosyllabic Dutch nouns, listed in the Appendix. Of these words, 30 end in alternating (e.g., *mand*), and 29 in non-alternating (e.g., *krant*) bilabial or alveolar plosives. The other 35 words end in labiodental or alveolar fricatives, of which 17 alternate in voice (e.g., *slaaf* 'slave' with the plural [slavən] *slaven*), and 18 are always voiceless (e.g., *bes* 'berry' with the plural [bɛsən] *bessen*).

We created a list containing two orthographic representations for each word. The word was spelled with a voiced final obstruent in one representation and with a voiceless obstruent in the other representation. Which representation is correct according to the spelling conventions of Dutch depends on the manner of articulation of the obstruent (plosive, fricative) and its realization in the word's morphological paradigm. The two versions of each word were presented right after each other, and the list thus started as follows: *baard*, *baart*, *baas*, *baaz*, *band*, *bant*, ... We asked a male speaker of Dutch, who makes a clear distinction between all voiced obstruents in Dutch and their voiceless counterparts, to record the words in the list. He was instructed to realize final obstruents as voiced, when they were represented as voiced, and to realize them as voiceless, when they were represented as voiceless. Although our speaker was not a phonetician, he did not need explicit instruction on how to realize word-final obstruents as voiced. Apparently, speakers of Dutch have ideas about how to realize word-final obstruents as voiced, even though voiced final obstruents do not occur in their language. The words were recorded on a DAT (BASF master 94) in a soundproof room by means of a portable DAT-recorder Aiwa HD S100 and a Sony microphone ECM MS957. The recordings were stored as .wav files (sample rate: 48 KHz) on a

computer by means of the speech analysis package *Praat* (Boersma 1996). Two phoneticians checked whether the final obstruents were realized as intended (voiced versus voiceless). If not, we asked our speaker to realize these words anew. In addition, we also asked our speaker to re-record words that he had realized with a schwa after the final obstruent.

We then carried out acoustic measurements in order to investigate whether our speaker had realized the final obstruents with incomplete neutralization, and how the voiced final obstruents differed from the voiceless ones. We first measured the durations of the vowels. We defined the beginning of the vowel as the beginning of a regular pattern in the wave form with the characteristics of the vowel, and the end of the vowel as the (sudden) end of this regular pattern. In addition, we measured the durations of the closures and release noises (the bursts plus the following periods of aspiration) of the final plosives, and the total durations of the final fricatives. We took the closure of the plosive to end at the sudden increase in amplitude at the beginning of the burst, and we assumed that the fricative and the release noise of the plosive end where the amplitude of the wave form is nearly identical to that of the background noise. Finally, we determined the proportion of the obstruent that was realized with vocal fold vibration. We assumed vocal fold vibration to be present if the waveform was periodic, the spectrogram contained a voice bar, and we could hear the vocal fold vibration in the acoustic signal.

The durations of vowels and final consonants in a word are, among others, affected by the presence and quality of extra consonants in the coda (Waals 1999). Since our data set contains only few words with complex codas, and since these words differ in the quality of the extra consonant, we restricted all our acoustic analyses to the words with simplex codas. We investigated by means of analyses of variance whether the durations were affected by the phonological length of the vowel (long versus short), the manner of the obstruent (plosive, fricative), the actual realization of this obstruent (voiced or voiceless), and its voice alternation (alternating, non-alternating).

For the duration of the vowel, we found significant main effects for phonological length ($F(1,101) = 654.09$; $p < 0.001$) and for the manner of the following final obstruent ($F(1,101) = 339.78$; $p < 0.001$). The phonologically long vowels were on average 99.2 ms longer than the phonologically short vowels, and the vowels preceding fricatives were on average 62.6 ms longer than the vowels preceding plosives. Furthermore, we observed an interaction between the phonological length of the vowel and the manner of the obstruent ($F(1,101) = 6.32$; $p = 0.014$). The difference between phonologically long and short vowels was less pronounced before plosives (81.5 ms) than before fricatives (101.9 ms). Finally, we observed an interaction between the manner of the obstruent and its actual realization ($F(2,101) = 4.30$; $p = 0.017$). Vowels preceding voiced fricatives were on average 16.0 ms longer than vowels preceding voiceless fricatives (see Figure 1, upper panel), whereas actual realization did not affect the duration of vowels preceding plosives (actual realization for plosives: $p > 0.1$). In many languages, voiced obstruents are preceded by longer vowels than voiceless obstruents. This is also the case for intervocalic obstruents in Dutch (Slis & Cohen 1969). In con-

trast, if a speaker of Dutch realizes word-final obstruents as voiced, apparently this does not necessarily affect the length of the preceding vowel.

The length of the final obstruent was affected by the manner of the obstruent ($F(1,109) = 108.35$; $p < 0.001$) and by its actual realization ($F(1,109) = 95.28$; $p < 0.001$). Fricatives were on average 52.2 ms longer than plosives, and voiced obstruents were on average 48.2 ms shorter than voiceless obstruents (see Figure 1, central panel). The length of a final obstruent may be a perceptual cue to its voicing.

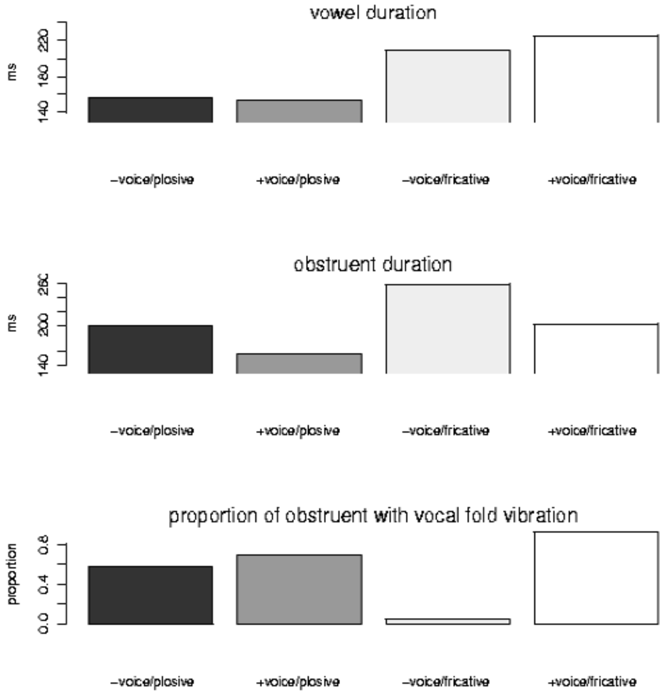

Figure 1: *The average duration of the vowel (upper panel), the average duration of the final obstruent (middle panel), and the average proportion of the final obstruent realized with vocal fold vibration (lower panel) for the words realized with voiced (+voice) and voiceless (–voice) final obstruents, broken for the manner of articulation of the final obstruent (plosive, fricative)*

We analysed separately the duration of the closure and the duration of the release noise for plosives. Closure duration was affected by the phonological length of the preceding vowel ($F(1,60) = 33.46$; $p < 0.001$), by the place of articulation (bilabial or alveolar) of the plosive ($F(1,60) = 19.60$; $p < 0.001$), and its actual realization ($F(1,60) = 159.95$; $p < 0.001$). Closures following phonologically long vowels (75.1 ms) were on average shorter than closures following short vowels (94.9 ms), and alveolar closures were on average shorter (82.1 ms) than bilabial

closures (104.4 ms). Interestingly, plosives that were actually voiced had longer closure durations (on average 108.9 ms) than plosives that were realized as voiceless (69.0 ms). This finding is in contrast with data for intervocalic positions, in which voiced plosives have shorter closures than voiceless plosives (e.g., Slis & Cohen 1969, Ernestus 2000). Probably, our speaker lengthened the voiced closures in order to have the presence of vocal fold vibration come out well. Vocal fold vibration is an important cue to voicing (see below), but preceding vowels mask the presence of vocal fold vibration in directly following closures, since they are relatively very loud. By lengthening the closures, our speaker made the presence of vocal fold vibration clearly audible. We also observed an interaction between the actual realization of the plosive and the phonological length of the preceding vowel ($F(1,60) = 8.94$; $p = 0.004$). Whereas the difference in closure duration between voiced and voiceless plosives was on average 33.6 ms after short vowels, it was 54.0 ms after long vowels. Finally, we observed an interaction between the actual realization of the plosive and its place of articulation ($F(1,60) = 15.45$; $p < 0.001$). The actual voice realization had a greater effect on the closures of alveolar plosives (average difference between voiced and voiceless alveolars: 49.8 ms) than on the closures of bilabial plosives (average difference: 16.7 ms).

The duration of the release noise was affected by the phonological length of the preceding vowel ($F(1,60) = 4.47$; $p = 0.039$) and by the actual realization of the plosive ($F(1,60) = 356.30$; $p < 0.001$). Release noises were longer after long vowels than after short vowels (on average 97.5 ms and 87.8 ms, respectively), and they were longer when the plosive was realized as voiceless than when it was voiced (on average 130.7 ms and 50.8 ms, respectively). The effect of the actual realization was larger (interaction between actual realization and place of articulation $F(1,60) = 16.58$; $p < 0.001$) for the alveolar plosives (the average release noise duration was 137.5 ms for [t]s, and 46.2 ms for [d]s) than for the bilabial plosives (average release noise duration for [p]s: 114.9 ms; for [b]s: 61.2 ms). Importantly, the duration of the release noise was also affected by the voice alternation of the plosive ($F(1,60) = 5.58$; $p < 0.001$). Release noises were shorter for alternating plosives (the average length was 84.7 ms) than for non-alternating plosives (93.7 ms). Our speaker realized the alternating plosives with weak voicing.

Finally, we analyzed the proportion of the obstruent that was realized with vocal fold vibration. The analysis of variance showed that the manner of the obstruent ($F(1,108) = 47.69$; $p < 0.001$) and its actual realization ($F(1,108) = 2568.41$; $p < 0.001$) affected the relative duration of vocal fold vibration in the obstruent. On average, 78.9% of the total duration of an actually voiced obstruent, and only 4.8% of a voiceless obstruent was realized with vocal fold vibration (see Figure 1, lower panel). This shows that our speaker realized final obstruents as voiced by keeping his vocal folds vibrating during a larger part of the obstruent. The difference between voiced and voiceless realizations was more pronounced for fricatives than plosives (interaction between actual realization and manner: $F(1,108) = 71.41$; $p < 0.001$). On average, both voiceless fricatives and voiceless plosives were realized with vocal fold vibration during less than 6.0% of their total dura-

tion (on average 3.5% and 5.8%, respectively), but voiced fricatives were realized with vocal fold vibration during 92.3%, and voiced plosives during 69.6% of their total duration.

In summary, our speaker signalled actual voicing especially by the presence of vocal fold vibration during a large part of the obstruent. In order to make the presence of vocal fold vibration well audible in plosives, he lengthened their closures. In addition, our speaker shortened voiced obstruents, and lengthened vowels preceding voiced fricatives (see also Figure 1). We found an effect of voice alternation only on the duration of the release noises, which suggests that our speaker only realized alternating plosives with weak voicing.

3. ***The rating experiment***

3.1 *Method*

For the rating experiment, we divided the word tokens over two master lists. Each master list contained only one realization of each word type, that is, it contained either the realization with the voiced final obstruent (e.g., [krɑnd]) or the realization with the voiceless final obstruent ([krɑnt]). Furthermore, each master list contained both voiced and voiceless final obstruents, and both alternating and non-alternating obstruents. The words ending in the same type of obstruent (alveolar plosive, bilabial plosive, alveolar fricative, and labiodental fricative) were blocked in order to keep the options (e.g., [p] or [b] or something in between) in a sequence of trials constant. This facilitates the participants' task, which was difficult since the participants were not used to judging speech sounds. Moreover, presenting the words in blocks might enhance the probability that participants would differentiate between the different tokens of obstruents of the same type. We created ten versions of each master list by randomizing the words in the blocks four times, while varying the order of the blocks. The resulting twenty lists are the lists with full words.

One group of participants listened to the full words, while another group listened to the rimes of the words starting at the steady states of the vowels. Thus, participants heard either [mɑnt], [hɔnd], etc., or [ɑnt], [ɔnd], etc. Since the rimes started at the steady state of the vowels, they contained no clear cues to the initial consonants, making it nearly impossible to trace the original words from which they had been spliced. Some of the initial consonants, however, might have been identifiable for some participants. In the worst case, this may have diminished the difference in scores between the participants hearing the full words and the participants hearing only the final rimes, which is the main interest of this study.

Vowels were shorter in the rimes, but since they all started at the steady states, the relative difference in duration between vowels preceding alternating and non-alternating obstruents was approximately the same in the words as in the rimes, as was also shown by a Linear Mixed Effect (LME) model (Pinheiro & Bates 2000, Baayen, Tweedie & Schreuder 2002). This LME analysis had the duration of the vowel as its dependent variable, type of presentation (word, rime), phonological vowel length (long, short), the manner of the final obstruent (plosive, fricative), its voice alternation (alternating, non-alternating), and its actual realization (voiced,

voiceless) as independent variables, and word type as random effect variable. It revealed a main effect for the type of presentation ($F(1,165) = 16.34$; $p < 0.001$). Unsurprisingly, vowels were longer in the words than in the rimes. In addition, the model revealed main effects for the phonological length of the vowel ($F(1,165) = 626.53$; $p < 0.001$), the manner of the final obstruent ($F(1,165) = 305.99$; $p < 0.001$), and the actual realization of the final obstruent ($F(1,165) = 8.31$; $p = 0.005$). These variables affected vowel duration as described in section 2. Finally, the actual realization of the obstruent interacted with the type of the obstruent ($F(1,165) = 36.87$; $p < 0.001$), also as described in section 2. Importantly, the type of presentation did not interact with voice alternation. We may therefore assume that the acoustic cues for incomplete neutralization, including release noise duration and cues that we did not discover, are roughly similar for the obstruents in both words and rimes.

Some forty-six percent of the rimes (43 rimes) represented existing words of Dutch by themselves. For instance, the rime of [klet] *kleed* ‘carpet’ with the plural [kledən] represents the existing verb [et] *eet* ‘eat’, which has the plural *eten* [etən]. The voice alternation for these words is independent of the voice alternation for the original words. We may therefore still expect that, if lexical intraparadigmatic information affects perception, the ratings for the full words will be more in conformity with the realizations of the obstruents in the words’ paradigms than the ratings for the rimes.

The participants were tested individually, sitting in a dimly lit room in front of a PC monitor and a panel with two buttons. They were asked to listen to the words that would be presented to them, and to rate the final obstruents, depending on the block, as [b]s or [p]s, as [d]s or [t]s, as [v]s or [f]s, or as [z]s or [s]s, or as something in between. Participants received for each block a response form with a five-point scale for every trial. The grapheme for the voiceless variant of the obstruent illustrated the left most position of the scale, while the grapheme for the voiced variant illustrated the right-most position. In (1), we present a line from the response form for the rating of alveolar plosives.

(1) t 0 0 0 0 0 d

The course of a trial was as follows. The participant heard a warning beep of 377 Hz for 500 ms, followed by a pause of 200 ms. The participant then heard the stimulus, and rated the voicing of the final obstruent on the five point scale. The experiment was self-paced. Participants were presented with a new word or rime only after they had indicated that they were ready by pushing the right button.

Forty undergraduate students of the Radboud University Nijmegen were paid to participate in the experiment. Twenty students listened to the full words, while the other twenty students listened to the rimes. The students were all native speakers of Dutch, and did not report any hearing deficits. Most of them originated from the southern part of the Netherlands, and may therefore be assumed to distinguish between the voiced and voiceless variants of both plosives and fricatives (Collins & Mees 1981:159, Gussenhoven & Bremmer 1983:57).

3.2 *Results and discussion*

Figure 2 presents the average scores by the participants who heard the final rimes (upper panel) and the participants who listened to the full words (lower panel). The left panels give the scores for the plosives, while the right panels list the scores for the fricatives. The scores are broken down for the realization of the final obstruent as intended by the speaker and the alternating/non-alternating character of the obstruent. A score of 1 indicates that the final obstruent was perceived as completely voiceless. A score of 5 indicates that the obstruent was completely voiced.

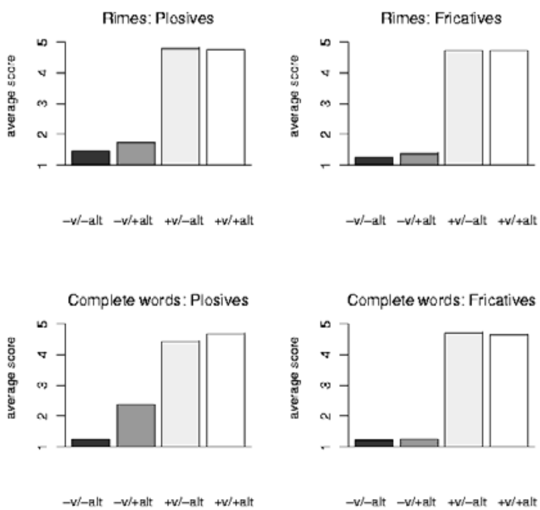

Figure 2: *The average scores for the final obstruents by the participants who heard only the rimes (upper panel) and the participants who heard the words (lower panel). The left panels show the scores for the plosives, while the right panels show the scores for the fricatives. The scores are broken for the actual realization of the final obstruent as voiced or voiceless (+v or –v) and its voice alternation (+alt or –alt)*

By means of a step-wise analysis of variance, we investigated whether the average scores for the items were affected by the type of presentation (rime, word), the actual realization of the final obstruent (voiced, voiceless), its voice alternation (alternating, non-alternating), and its manner of articulation (plosive, fricative). We removed four outlier stimuli (*hond* and *dood* both realized with [t], *schub* realized with [b], and *slurf* realized with [v]) from the data set in order to improve the normality of the model's residuals. The results are presented in Table 1.

Effects	DF	F-value	p-value
Manner	1	60.90	< 0.001
Alternation	1	87.58	< 0.001
Realization	1	12050.30	< 0.001
Manner: Alternation	1	40.02	< 0.001
Manner: Realization	1	64.12	< 0.001
Alternation: Realization	1	52.30	< 0.001
Alternation: Presentation	2	16.04	< 0.001
Realization: Presentation	1	23.03	< 0.001
Manner: Alternation: Realization	1	16.08	< 0.001
Manner: Alternation: Presentation	2	14.40	< 0.001
Manner: Realization: Presentation	1	14.42	< 0.001
Alternation: Realization: Presentation	1	8.49	0.004
Manner: Alternation: Realization: Presentation	1	6.63	0.010

Table 1: *Results of the stepwise analysis of variance of the average scores*

Figure 2 clearly shows that, unsurprisingly, by far the most important predictor for the average scores is the actual realization of the final obstruent. Whereas voiced obstruents were assigned an average score of 4.69, voiceless obstruents received an average score of only 1.54. This shows that listeners are sensitive to the acoustic cues of vowel duration, obstruent duration, and relative duration of vocal fold vibration for voicing.

Voice alternation also is an important factor (see Table 1). Scores were on average 0.28 higher for alternating obstruents than for non-alternating obstruents, but, as is clear from Figure 2, the effect is mainly carried by the voiceless plosives (as is supported by the interactions between voice alternation and manner of articulation, between voice alternation and actual realization, and between voice alternation, manner of articulation, and actual realization, as reported in Table 1). Whereas the average effect of voice alternation did not exceed 0.10 for the fricatives and the voiced plosives, it was 0.70 for the voiceless plosives. The focus of this study is on the interaction between voice alternation and type of presentation. Figure 2 suggests that an interaction is present for the voiceless plosives and the voiced plosives, but that it is absent for the fricatives. This is supported by separate analyses of variance on these four types of obstruents (see Table 2), as well as by the interactions between voice alternation and type of presentation with manner of articulation and actual realization in the overall analysis (Table 1). Voice alternation affects the rating for the voiceless plosives both in the rime condition ($F(1,55) = 6.99$; $p = 0.011$) and in the full word condition ($F(1,56) = 151.11$; $p < 0.001$), but the effect in the full word condition is larger (on average 1.11 in the full word condition versus 0.27 in the rime condition). The interaction between voice alternation and type of presentation is weaker for the voiced plosives than for the voiceless plosives (an analysis of just the plosives shows an interaction between voice alternation, type of presentation, and actual realization: $F(1,225) = 12.12$; $p < 0.001$), but again voice alternation has a larger effect on the

full words than on the rimes (an insignificant average difference of –.04 for the rimes and a significant difference of 0.24 for the full words). Since the words and the rimes do not differ in acoustic incomplete neutralization, the interaction of voice alternation with type of presentation must be due to lexical information that listeners access upon hearing words. The difference between words and rimes therefore shows that, at least for the final plosives in words, the effect of voice alternation is not only mediated by incomplete neutralization in the acoustic signal.

Type of obstruent	F-value	p-value
Voiceless plosives	38.04	< 0.001
Voiced plosives	10.00	0.002
Voiceless fricatives	0.70	> 0.1
Voiced fricatives	0.33	> 0.1

Table 2: *The interaction between voice alternation and type of presentation in separate analyses of variance of the average scores for the four types of final obstruents*

The interaction between voice alternation and type of presentation may be smaller for the voiced plosives than for the voiceless plosives, because the voiced realizations were unnatural for the listeners, who consequently scored nearly all voiced realizations as completely voiced. In addition, we may be observing a ceiling effect, because the voiced obstruents were already maximally voiced. The absence of an interaction for fricatives suggests that their voiced-voiceless opposition is too weak for our listeners, that is, there is not sufficient intraparadigmatic information for listeners to rely on for fricative final words.

The effects of the actual realization on the rating scores support the hypothesis that the ratings for the plosives in the full word condition were affected by lexical information. The obstruent's realization is expected to have a larger effect on the rating scores when listeners rely more on the acoustic signal. We find that while the difference between voiced and voiceless fricatives is approximately the same in the rime and in the full word condition, the difference in scores between voiced and voiceless plosives is smaller for words than for rimes (2.76 versus 3.20; see the interaction between actual realization, type of presentation, and manner of articulation given in Table 1). Apparently, listeners based their ratings less on the acoustic signal when they could identify the word (full word condition) and the obstruent was a plosive. In these cases, listeners based their ratings also on the paradigm of the word.

Our results hardly change if we restrict our analysis to the words of which the rimes are not existing words of Dutch by themselves. Such an analysis shows exactly the same main effects and interactions, except that the interaction between voice alternation, actual realization, and type of presentation is missing, probably due to the smaller number of data points. This shows that the effect of voice alternation on the scores for the rimes cannot be due only to the rimes that represent words by themselves, and thus to intraparadigmatic information that listeners ac-

cess upon hearing these rimes. The effect of voice alternation on the rimes is mainly due to incomplete neutralization in the signal.

In conclusion, alternating voiceless plosives were rated as more voiced than nonalternating voiceless plosives, especially when presented in full words. This finding shows that intraparadigmatic effects on listeners' voicing rates are mediated not only by incomplete neutralization in the acoustic signal, but also by listeners' paradigmatic knowledge.

4. *General discussion and conclusion*

This study addresses the question of whether intraparadigmatic effects in perception are mediated only by incomplete neutralization in the acoustic signal. We carried out a transcription experiment in which Dutch listeners who were not phonetically trained were presented with either full words or the final rimes of these same words, and were asked to rate the final obstruents as voiced or voiceless on a five point scale. Half of the words end in obstruents that are generally realized as voiceless, while the other half end in obstruents that alternate in voice, that is, are realized as voiced in some members of the words' paradigms.

The stimuli were recorded by a speaker of Dutch who realized final obstruents as voiced mainly by shortening them and realizing them with vocal fold vibration during a longer period. He lengthened preceding vowels only for fricatives. Interestingly, the cues that our speaker used to signal voicing were different from the cues that are used by speakers of English, for whom the duration of the preceding vowel is a major cue for all types of obstruents (e.g., Denes 1955). This difference may help explain the difficulties that speakers of Dutch experience with the voicing of word-final obstruents in English: Dutch speakers may focus on acoustic cues that are less relevant for English.

Acoustic analyses showed an effect of voice alternation only on the durations of the release noises of plosives. This is in line with the study by Ernestus and Baayen on pseudowords (2006), in which voice alternation was also found to affect only release noise duration. Possibly, we found no effect of voice alternation on vowel duration, in contrast to Warner et al. (2004), because the words with alternating and non-alternating obstruents in our experiment differed in their phonological make-up (i.e., they were not minimal pairs), and differences caused by the surrounding environment obscured any systematic vowel duration difference.

The main predictor for the average voicing scores by the listeners was the voice realization as intended by the speaker. In addition, scores were higher for alternating plosives than for non-alternating plosives. For the voiceless plosives, this was the case both in the rime and in the full word condition, while for the voiced plosives it was only so in the full word condition. Participants listening to rimes could not well identify the presented words in most cases, and their rating must therefore have been based mainly on the acoustic signal. We think that the intraparadigmatic effects on their scores are predominantly the result of incomplete neutralization in the acoustic signal, and therefore made possible by intraparadigmatic effects in production. In contrast, participants listening to full words could identify the presented words in all cases, and their scores could there-

fore be strongly affected by lexical knowledge as well. Indeed, the intraparadigmatic effects observed for the voiceless plosives were greater in the full word condition than in the rime condition. This shows that the knowledge of a word's paradigm also affects the interpretation of voicing. We conclude that intraparadigmatic effects in perception are partly mediated by the acoustic signal, and partly induced by the listener's lexical knowledge.

Note that our transcribers' intraparadigmatic knowledge in fact prevented them from basing their scores completely on the acoustic signal. Clearly, at least for non-trained transcribers, intraparadigmatic knowledge is in the way of phonetic transcriptions, intended as objective representations of the acoustic signal. Thus intraparadigmatic knowledge presents another problem for objective phonetic transcriptions, which Vieregge (1987) already claimed to be impossible. Furthermore, this finding also shows that intraparadigmatic effects mediated by listeners' lexical knowledge are automatic. They arise even when this is counterproductive for the task that listeners have to carry out.

The intraparadigmatic effects in perception mediated by the listeners' knowledge may well be the motor behind incomplete neutralization in the acoustic signal in production. The alternating and non-alternating obstruents that were voiceless differed in their scores by only 0.21 in the rime condition but 0.73 in the full word condition. In other words, listeners' knowledge of the morphological paradigms give rise to an effect in the ratings that may be two times as big (0.73–0.21 versus 0.21) as that caused just by incomplete neutralization in the acoustic signal. The differences that listeners perceive between alternating and non-alternating obstruents is magnified by their knowledge of the paradigms, and this may encourage them to maintain these differences in their speech.

The intraparadigmatics of perception reported here instantiate in fact a subtle form of paradigmatic levelling. Steriade (2000) claims that paradigmatic levelling may affect phonemes as well as subphonemic characteristics. What we have shown here is that subphonemic paradigmatic levelling is not restricted to production, but is also a characteristic of perception.

Only the scores for final plosives were clearly affected by the words' paradigms. Recall that we found no evidence for incomplete neutralization in the signal for fricative-final words. This may explain why the alternating character of final fricatives did not affect the scores by the participants who heard just the final rimes. The fact that also the participants listening to the full words showed no effects, even though they could rely on their intraparadigmatic knowledge, may be explained by the weakness of the voiced-voiceless opposition for fricatives in Dutch. This opposition is not well maintained by most speakers of Dutch, it is hardly distinctive after vowels, and it is not supported by the spelling conventions of Dutch in syllable-final position.

Our listeners scored those voiceless obstruents as slightly voiced that are spelled as voiced. Nevertheless, the intraparadigmatic effects reported here cannot only be due to orthography, since our participants also showed sensitivity to incomplete neutralization in the signal when listening to rimes that do not represent words by themselves, and for which they consequently could not rely on the spell-

ing. Moreover, also other studies show that intraparadigmatic effects on the production and comprehension of voicing can be independent of orthography. As already mentioned in section 1, Dinnsen & Charles-Luce (1984) and Charles-Luce (1993) have shown that incomplete neutralization is also present in Catalan minimal word pairs for which the spelling does not reflect the difference between alternating and non-alternating obstruents. Furthermore, we have shown in a previous study that Dutch listeners are sensitive to weak voicing in fricatives, even though voiceless fricatives are always spelled as voiceless (Ernestus & Baayen 2006). Finally, we also have evidence that intraparadigmatic effects that are not mediated by incomplete neutralization do not just result from orthography. In a follow-up study (Ernestus & Baayen 2007), we presented the stimuli from the present rating experiment in a lexical decision experiment. We found that the frequency with which an alternating plosive is realized as voiced relative to the frequency with which it is voiceless affects response latencies. This frequency effect cannot be due to orthography, since both the voiced and voiceless realizations for alternating plosives are spelled as voiced. Intraparadigmatic effects need not be supported by orthography.

We now turn to the question of how to incorporate our findings in the grammar of Dutch. In generative grammar, intraparadigmatic effects are traditionally accounted for by means of underlying forms. A morpheme-final obstruent that is voiced before vowel-initial suffixes is also voiced in the underlying form, as already mentioned in the introduction of this paper. Thus, the underlying form of [mɑnt] is /mɑnd/ because of the voiced [d] in the plural [mɑndən]. Incomplete neutralization can be accounted for by the assumption that the voicing of the final obstruent in the underlying form affects the production of the obstruent via phonetic implementation rules preceding or coinciding with Final Devoicing, or replacing Final Devoicing (Dinnsen & Charles-Luce 1984, Port & O'Dell 1985, Slowiaczek & Dinnsen 1985).

A generative account of the data with a rule (or constraint) of Final Devoicing supplemented with various independent phonetic implementation rules (or constraints) is possible, but cumbersome. What is required to account for the data is (1) information as to whether a word-final (voiceless) obstruent is alternating, (2) Final Devoicing, and (3) phonetic implementation rules (constraints) that weakly (re)voice voiceless obstruents. By Occam's razor, we prefer a theory in which phonetic realization rules directly produce the correct form from the alternation information in the lexicon to a theory that devoices underlyingly voiced segments while partly re-voicing them in another stage in the derivation. In the OT-framework, we prefer a theory in which the constraint of Final Devoicing is simply dispensed with.

This line of argument can be taken a step further, since the mental lexicon contains form representations for a great many words, including inflected forms (e.g., Jackendoff 1975, Baayen, Dijkstra & Schreuder 1997, Alegre & Gordon 1999, Baayen, McQueen, Dijkstra & Schreuder 2003). Given that nearly every word is lexically represented, we may assume lexical representations that directly reflect the words' pronunciations. That is, the singular *mand* may be represented as

/mɑnt/ and the plural *manden* as /mɑndən/. As a consequence, all theoretical approaches based on lexical representations that do not reflect actual pronunciation are unnecessarily complex, irrespective of whether they assume Final Devoicing. Hence, by Occam's razor, we also disprefer accounts in which phonetic implementation rules are directly applied to underlying voiced obstruents or to archiphonemes unspecified for voice (cf. Trubetzkoy 1958, Lieb 1998), even though these accounts can easily incorporate incomplete neutralization.

Following Bybee (2001; see also Ernestus & Baayen 2006), we view intraparadigmatic effects in production and perception as resulting from lexical analogy that is not mediated by abstract underlying representations nor by an idiosyncratic feature that marks a final obstruent as alternating or non-alternating. When speakers realize [mɑnt] in production, they activate [mɑnt] as well as [mɑndən]. The plural contains [d], which may affect the realization of the word-final [t], resulting in weak voicing. In contrast, when speakers realize [krɑnt], the inflectional paradigm members do not contain [d], and they do not slightly voice the word-final obstruent.

Lexical analogy can also explain intraparadigmatic effects in perception. When listeners perceive a word, this word as well as the morphologically related words are activated in the listeners' mental lexicon, and these paradigmatic competitors codetermine the listeners' percept. Formalized analogical models, such as Skousen's Analogical Model of Language (Skousen 1989, 1993), can easily incorporate these intraparadigmatic effects.

One of the predictions of our approach, that we leave for further research, is that alternating intervocalic voiced obstruents would be realized and perceived as less voiced than their non-alternating counterparts. For instance, the alternating [d] of Dutch [bɪdən] *bidden* 'to pray' (with the singular present-tense [bɪt] *bid*) would be produced and perceived as less voiced than the non-alternating [d] of [mɪdən] *midden* 'middle'. Note that under a generative account with abstract underlying representations, we would not expect a difference between [bɪdən] and [mɪdən], since both forms underlyingly contain /d/ (/bɪdən/, /mɪdən/). Thus, alternating and non-alternating voiced intervocalic obstruents would form a good test case for the generative account and the lexical paradigmatic account.

To conclude, the main point of this study is that the intraparadigmatic realization of an obstruent does not only affect its production but also its perception. The intraparadigmatic effects in perception are partly mediated by incomplete neutralization in the acoustic signal, and partly arise due to listeners' lexical knowledge. These intraparadigmatic effects are automatic, and prevent listeners from producing accurate phonetic transcriptions that are true reflections of the acoustic signal itself.

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Appendix

Experimental words ending in obstruents that are voiced in inflectionally related words:

krib	‘manger’	*kleed*	‘cloth’	*grens*	‘border’
kwab	‘lobe’	*koord*	‘cord’	*hals*	‘neck’
rib	‘rib’	*maand*	‘month’	*kaas*	‘cheese’
schub	‘scale’	*mand*	‘basket’	*laars*	‘boot’
web	‘web’	*moord*	‘murder’	*muis*	‘mouse’
baard	‘beard’	*naald*	‘needle’	*neus*	‘nose’
bed	‘bed’	*oord*	‘place’	*prijs*	‘price’
brand	‘fire’	*paard*	‘horse’	*spijs*	‘food’
brood	‘bread’	*strand*	‘beach’	*korf*	‘basket’
bruid	‘bride’	*tand*	‘tooth’	*scherf*	‘fragment’
dood	‘dead’	*veld*	‘field’	*slaaf*	‘slave’
eend	‘duck’	*vod*	‘rag’	*slurf*	‘trunk’
hand	‘hand’	*woord*	‘word’	*staaf*	‘bar’
held	‘hero’	*zwaard*	‘sword’	*wolf*	‘wolf’
hemd	‘shirt’	*baas*	‘boss’	*zalf*	‘ointment’
hond	‘dog’	*gans*	‘goose’		

Experimental words ending in obstruents that are always voiceless:

klap	‘bang’	*lat*	‘slat’	*fles*	‘bottle’
mep	‘clout’	*lint*	‘ribbon’	*kous*	‘stocking’
schep	‘scoop’	*maat*	‘measure’	*pols*	‘wrist’
stip	‘dot’	*mot*	‘moth’	*tas*	‘bag’
strip	‘strip’	*pet*	‘cap’	*tros*	‘cluster’
beurt	‘turn’	*pit*	‘pip’	*vis*	‘fish’
cent	‘cent’	*poort*	‘gate’	*zeis*	‘scythe’
fluit	‘flute’	*put*	‘well’	*bef*	‘jabot’
geit	‘goat’	*schat*	‘treasure’	*juf*	‘female teacher’
grot	‘cave’	*scheut*	‘twinge’		
hert	‘deer’	*spruit*	‘sprout’	*nimf*	‘nymph’
kat	‘cat’	*staart*	‘tail’	*plof*	‘thud’
klant	‘customer’	*bes*	‘berry’	*rif*	‘reef’
knot	‘knot’	*bos*	‘woods’	*slof*	‘slipper’
krat	‘crate’	*dans*	‘dance’	*straf*	‘punish-ment’
kreet	‘cry’	*eis*	‘require-ment’		
krot	‘slum’				

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